

**NASA TECHNICAL
MEMORANDUM**

NASA TM X-71625

NASA TM X-71625

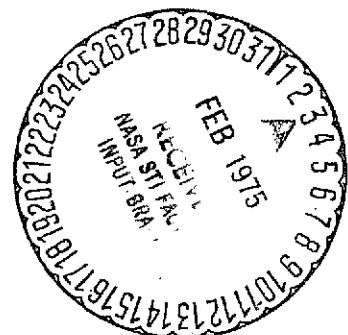
(NASA-TM-X-71625) NASA LEWIS 10 BY 10 FOOT
SUPERSONIC WIND TUNNEL (NASA) 47 P HC \$3.75
CSCL 01E

N75-14780

63/09 Unclass
07711

NASA LEWIS 10- BY 10-FOOT SUPERSONIC WIND TUNNEL

by Robert A. Aiello
Lewis Research Center
Cleveland, Ohio 44135
November 1974



1. Report No. TM X-71625		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle NASA LEWIS 10- BY 10-FOOT SUPERSONIC WIND TUNNEL				5. Report Date	
				6. Performing Organization Code	
7. Author(s) by Robert A. Aiello				8. Performing Organization Report No. E-8151	
				10. Work Unit No.	
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135				11. Contract or Grant No.	
				13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract Performance data are presented for this tunnel, which has a Mach number range from 2.0 to 3.5. Also described are the tunnel circuit, model support systems, auxiliary systems, instrumentation, control room equipment, and automatic recording and computing equipment. Information is presented on criteria for designing models and on shop facilities available to users.					
17. Key Words (Suggested by Author(s))				18. Distribution Statement Unclassified - unlimited	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages	
				22. Price*	

TABLE OF CONTENTS

	Page
GENERAL TUNNEL DESCRIPTION	1
Aerodynamic Cycle	1
Propulsion Cycle	1
Tunnel Components	1
Air dryer	1
Cooler 2	2
Compressor 2	2
Air heater	2
Flexible-wall nozzle	2
Test section	2
Second throat	2
Cooler 1	2
Compressor 1	2
Valve 13	2
Exhaust muffler	3
Exhauster system	3
TUNNEL AERODYNAMIC PERFORMANCE	3
Aerodynamic Cycle	3
Propulsion Cycle	3
Tunnel-Air Heater	3
TEST SECTION DESCRIPTION	4
MODEL SUPPORTS	5
Sting Strut	5
Ceiling Strut Assembly	5
Auxiliary Strut	6

E-8151

	Page
AUXILIARY SYSTEMS	7
Air Systems	7
High pressure air	7
Variable pressure air	7
Service air	7
Hydraulic System	7
Fuel System	7
INSTRUMENTATION AND SUPPORTING EQUIPMENT	8
Force Measurement Systems	8
Sting strut	8
Ceiling strut	10
Calibration	10
Angle-of-Attack Indicator	10
Thermocouples	10
Schlieren System	11
DATA ACQUISITION AND PROCESSING	11
Central Facility Data Recording	11
CADDE II	11
Multiple pressure scanning system	12
Central analog recording system	13
Local Analog Recording System	13
Data Processing	13
On-line time sharing	14
Off-line batch processing	14
Off-line analog processing	14

	Page
MODEL INFORMATION	15
Model Size	15
Model Design Criteria	15
Steady-state loads	15
Supersonic starting loads	15
Pressure Instrumentation	16
Thermocouple Wiring	16
Actuators and Position Indicators	17
Electrical Cables	17
Power cables	17
Signal cables	17
 FACILITIES AVAILABLE TO USERS	 19
Model Stands	19
Machine Tools and Lifts	19
Electrical Systems	20

GENERAL TUNNEL DESCRIPTION

The 10 X 10 Foot Supersonic Wind Tunnel is capable of attaining test section flow in the Mach number range from 2.0 to 3.5 in increments of 0.1. The tunnel may be operated in either of two modes; aerodynamic cycle or propulsion cycle.

Aerodynamic Cycle

During the aerodynamic cycle the tunnel is operated as a closed system with dry air added only as required to maintain the desired tunnel conditions. This cycle is used primarily for aerodynamic flow studies where contaminants are not introduced into the airstream. Figure 1(a) illustrates the air flow path for the aerodynamic cycle.

Propulsion Cycle

During the propulsion cycle the tunnel is operated as an open system with the air continuously drawn through the air dryer and exhausted to the atmosphere. This cycle is used for models which introduce contaminants into the airstream and also when the tunnel-air heater system is utilized. Figure 1(b) illustrates the air flow path for the propulsion cycle.

Tunnel Components

Major components of the Lewis 10 X 10 Supersonic Wind Tunnel are illustrated in figure 2. These components are:

Air dryer. - The air dryer removes moisture from atmospheric air prior to its introduction into the tunnel. It contains 1.724×10^6 kg (1900 tons) of activated alumina in six beds each 0.91 m (3 ft) thick. The dryer is designed to pass 834 kg/sec (1838 lb/sec) of air entering at 29° C (85° F) with a dewpoint of 23° C (73° F) and leaving with a dewpoint of -40° C (-40° F) for a 2 hour period. Reactivation of the activated alumina requires 4 hours heating and 4 hours cooling.

Cooler 2.- Cooler 2 is a finned-tube water type heat exchanger, used to cool the air entering compressor 2. It is designed to reduce the temperature from 177° C (350° F) to 49° C (120° F) with a pressure drop of 25.4 cm (10 in.) of water. The airflow capacity of the cooler is 1210 kg/sec (2670 lb/sec).

Compressor 2.- Compressor 2 is a 10 stage axial-flow compressor, rated at a volume of 623 m³ (22 000 ft³) of air per second at a pressure ratio of 2.4. It is driven by three wound-rotor induction motors having a total power capacity of 74 600 kW (100 000 hp).

Air heater.- The air heater system utilizes the combustion of natural gas in the tunnel airstream to raise the air temperature to 634° K (1140° R). Use of this heater is limited to the propulsion cycle.

Flexible-wall nozzle.- The flexible-wall nozzle produces supersonic flow in the test section; it consists of two flexible side walls of stainless steel 3.048 m (10 ft) high, 23.15 m (76 ft) long, and 3.49 cm (1-3/8 in.) thick which are actuated by hydraulically operated screwjacks. The top and bottom plates are fixed.

Test section.- The test section is 12.19 m (40 ft) long, has a cross section of 3.048 x 3.048 m (10 x 10 ft) at the entrance, and is 3.048 m (10 ft) high by 3.203 m (10.51 ft) wide at the exit.

Second throat.- The second throat is used to conserve power by reducing the Mach number at the terminal shock wave. The side walls are moveable; each consisting of two hinged plates actuated by electrically driven screwjacks. The top and bottom plates are fixed.

Cooler 1.- Cooler 1 is a finned-tube water type heat exchanger, used to cool the air entering compressor 1. It is designed to reduce the temperature from 343° C (650° F) to 49° C (120° F) with a pressure drop of 7.62 cm (3 in.) of water. The airflow capacity of the cooler is 853 kg/sec (1880 lb/sec).

Compressor 1.- Compressor 1 is an 8 stage axial-flow compressor, rated at a volume of 2200 m³ (78 000 ft³) of air per second at a pressure ratio of 2.8. It is driven by four wound-rotor induction motors having a total power capacity of 112 000 kW (150 000 hp).

Valve 13.- Valve 13 is a 7.32 m (24 ft) diameter swinging-type valve, used to place the tunnel in either the

aerodynamic or propulsion cycle of operation.

Exhaust muffler.- The exhaust muffler is used to quiet the discharge air when the tunnel is operated on the propulsion cycle.

Exhauster system.- The exhauster system consists of two piston-type exhausters, having a total capacity of 2830 m³ (100 000 ft³) of air per minute. The exhausters reduce the air density in the tunnel when the tunnel is operated on the aerodynamic cycle.

TUNNEL AERODYNAMIC PERFORMANCE

Aerodynamic Cycle

Operating characteristics of the tunnel for the aerodynamic cycle are given in figure 3. It shows the test section altitude, dynamic pressure, Reynolds number, total pressure, and total temperature versus the test section Mach number over the tunnel operating range.

Propulsion Cycle

Operating characteristics of the tunnel for the propulsion cycle are given in figure 4. It shows the test section altitude, dynamic pressure, Reynolds number, total pressure, and total temperature versus the test section Mach number over the tunnel operating range.

Tunnel-Air Heater

The effects of tunnel-air heater operation during the propulsion cycle are shown in figure 5. Variations of tunnel airflow total temperature with free-stream Mach numbers are given. The increase in temperature at Mach 2.5 is the result of operation of the secondary compressor, the main compressor being in operation at all speeds. The flight stagnation temperature variation in the tropopause is also shown in figure 5 for reference. The difference

between these curves is the temperature rise required of the heater in order to simulate flight. The heater was designed to equal or exceed this required temperature rise up to a maximum of 634° K (1140° R). This maximum temperature is limited by the thermal expansion of the tunnel structure. Further information on the effects of the heater can be found in NASA TM X-1636, entitled "Water Condensation Effects of Heated Vitiated Air on Flow in a Large Supersonic Wind Tunnel".

TEST SECTION DESCRIPTION

The test section plan view, cross section, and elevation views are shown in figures 6, 7, and 8 respectively. The upstream cross section at the end of the flexible-wall nozzle is 3.048 x 3.048 m (10 x 10 ft). The 3.49 cm (1-3/8 in.) thick stainless steel side walls diverge 0° 22' each to a width of 3.203 m (10.51 ft) at the downstream end. The top and bottom plates are parallel to each other. The location of the test rhombus is shown in figure 6.

The floor of the test section can be lowered to the first floor level by means of screwjacks at each corner. Model installation is generally made through the resulting 10.067 m (33 ft 4-1/8 in.) by 3.048 m (10 ft) opening. A special model dolly can be used to move the model onto the floor plate. Two 22 700 kg (25 ton) traveling overhead cranes capable of running the length of the building housing the test section are available for model installation. These cranes have 4540 kg (5 ton) auxiliaries.

There are removable top and bottom plates in the test section which are available for installation of small model supports and auxiliary apparatus. The opening may vary up to 6.10 m (20 ft) long by 1.07 m (3.5 ft) wide depending upon the selection of insert plates. Model mountings, described under the section on MODEL SUPPORTS, are installed through these openings.

Three pairs of 0.84 m (33 in.) diameter windows are located in the side walls of the test section as shown in figure 8. Two pairs of these windows are mounted eccentrically in 1.52 m (5 ft) diameter movable disks. The disks may be rotated to position the windows on a 0.267 m (10.5 in.) radius. The third pair of windows is located in a fixed position downstream of the movable windows.

Personnel access doors 0.91 x 2.13 m (3 x 7 ft) are located opposite each other at the downstream end of the test section.

MODEL SUPPORTS

Sting Strut

The strut for sting-mounted models, shown in figure 9(a), is extended through the tunnel floor when in use. The strut centerline may be located between 4.24 m (13 ft 11 in.) and 7.14 m (23 ft 5 in.) from the floor joint datum line in 15.24 cm (6 in.) increments. The strut has a chord length of 1.22 m (4 ft) and is 20.32 cm (8 in.) thick.

The strut can be rotated in the vertical plane about a pin located 24.13 cm (9.5 in.) below the test section floor. The angle of attack can be remotely varied from -5° to $+20^\circ$. The maximum radius of rotation is 2.08 m (6 ft 10 in.), and the minimum radius is determined by interference of the strut socket with the tunnel floor.

A terminal panel is located in the top of the strut for all electrical and pressure connections from the model. This panel is accessible by removing the fairings from the sting socket.

Allowable sting loads are indicated in figure 9(a). Details of the sting end that mates with the strut are shown in figure 9(b).

An adapter, shown in figure 10, is available to permit the use of stings originally made for the NASA Lewis Research Center 8 x 6 Foot Supersonic Wind Tunnel.

Ceiling Strut Assembly

A ceiling strut assembly with a typical model installed is shown in figure 11. This assembly consists of the strut proper to which the model is attached, and the anchoring structure and angle-of-attack mechanism which are outside the test section.

Strut thickness may vary up to 25.4 cm (10 in.) and the chord length up to 2.13 m (7 ft). The maximum chord length is determined by the angle-of-attack requirement.

Angle of attack of the model is remotely controlled by a screwjack mechanism which rotates the strut around a 7.62 cm (3 in.) diameter pin located 17.78 cm (7 in.) above the inside surface of the tunnel top plate. The screwjack can be mounted on either end of the strut housing, depending on clearances to the tunnel structure. The angle-of-attack range is determined by model size and strut attachment details.

The center of rotation of the strut may be positioned along the top of the tunnel in 15.24 cm (6 in.) increments between 3.56 m (11 ft 8 in.) and 6.60 m (21 ft 8 in.) from the ceiling joint datum line. This is without special insert plates.

Electrical wiring from the strut is connected to terminal panels on top of the test section. Pressure tubing is connected to Scanivalves located on top of the test section.

Auxiliary Strut

An auxiliary strut, shown in figure 12, is provided to hold a nozzle plug-actuating mechanism or tail rake when a suspended model is used. The mechanism used should fit the flange on the end of the strut which is detailed in figure 12. The strut is designed to rotate about the ceiling strut center of rotation at a radius of 3.73 m (12 ft 3 in.). The leading edge of the strut may be located a minimum of 2.87 m (9 ft 5 in.) and a maximum of 7.29 m (23 ft 11 in.) from the ceiling joint datum line, with positioning in 15.24 cm (6 in.) increments. There are three additional positions for this strut at 8.97 m (29 ft 5 in.), 9.12 m (29 ft 11 in.), and 9.27 m (30 ft 5 in.) from the ceiling joint datum line.

All electrical and pressure connections on top of the test section are the same as used with the ceiling strut.

AUXILIARY SYSTEMS

Air Systems

High pressure air. - A storage facility is available with a capacity of 6120 m^3 ($216\,000 \text{ ft}^3$) of standard dry air at $1.83 \times 10^7 \text{ N/m}^2$ (2650 psi) for use at the tunnel. Two other air storage facilities are interconnected with it. These are a 4110 m^3 ($145\,000 \text{ ft}^3$) system located at the 8x6 Wind Tunnel and a $17\,600 \text{ m}^3$ ($620\,000 \text{ ft}^3$) system located at the 9x15 Test Section. The three facilities together provide a total capacity of $27\,800 \text{ m}^3$ ($981\,000 \text{ ft}^3$) of standard dry air for use at the 10x10 Wind Tunnel. They are charged by a pump having a capacity of $0.24 \text{ m}^3/\text{sec}$ ($500 \text{ ft}^3/\text{min}$) of standard air. Total charging time from $2.76 \times 10^6 \text{ N/m}^2$ (400 psi) to $1.83 \times 10^7 \text{ N/m}^2$ (2650 psi) is approximately 28 hours for the combined systems.

Variable pressure air. - A variable pressure system with a capacity of 45.4 kg/sec (100 lb/sec) is available at pressures up to $1.03 \times 10^6 \text{ N/m}^2$ (150 psi).

Service air. - A service air system with a capacity of 0.91 kg/sec (2 lb/sec) continuous service is available at $8.62 \times 10^5 \text{ N/m}^2$ (125 psi).

Hydraulic System

A hydraulic system is available for actuation or positioning of a model and/or its components. This system consists of three pumps each rated at $1.26 \times 10^{-3} \text{ m}^3/\text{sec}$ (20 gal/min). The pumps are connected in parallel and may be used in any combination. The maximum capacity of the system is $3.79 \times 10^{-3} \text{ m}^3/\text{sec}$ (60 gal/min) at $2.07 \times 10^7 \text{ N/m}^2$ (3000 psi).

Fuel System

The liquid fuel system is made of stainless steel and has a total flow capacity of $4.42 \times 10^{-3} \text{ m}^3/\text{sec}$ (70 gal/min) at $2.76 \times 10^5 \text{ N/m}^2$ (40 psi). The maximum pressure available is $6.55 \times 10^6 \text{ N/m}^2$ (950 psi) at a flow of $1.89 \times 10^{-3} \text{ m}^3/\text{sec}$

(30 gal/min). Fuel is filtered to 10 micron particle size before delivery to the test section.

INSTRUMENTATION AND SUPPORTING EQUIPMENT

Force Measurement Systems

Sting strut. - To measure forces on models mounted on the sting strut four different size balances are available. These are three-component bearing type strain gage balances incorporating Baldwin SR-4 strain gages mounted on cantilever beams. The three components measured are axial force, front normal force, and rear normal force. There are alternate strain gage links available for each balance resulting in a wide range of capacities. The table on the following page lists the maximum loads and alternate links for each balance. Figures 13, 14, 15, and 16 show the 6.35 cm (2-1/2 in.), 10.16 cm (4 in.), 12.70 cm (5 in.), and 17.78 cm (7 in.) diameter balance systems respectively.

The strain gage links can sustain momentary overloads up to 200 percent of rated capacity without damage to the strain gages. Structurally these links can take 500 percent of rated capacity before failure.

If it becomes necessary to reduce displacements or increase pitching moment capacity for a particular model two balances may be used. Such a system would have to be planned specifically for the model.

Following is a list of sting-mounted balance systems and alternate force measurement links available.

Maximum Loads

Balance	2-1/2"	4"	5"	7"
Lift lb	900	2500	6000	16000
Drag lb	350	1800	4000	10000
Pitching Moment in-lb	7200	30000	90000	336000
Lateral Force lb	3600	8000	18000	32000
Rolling Moment in-lb	3420	9000	23000	57000
Yawing Moment in-lb	11700	30000	88000	232000

Alternate Links

Balance	2-1/2"	4"	5"	7"
Lift Links lb	100	100	250	2000
	200	200	500	5000
	300	400	1000	8000
	500	600	2000	12000
	700	1000	3000	16000
	900	1500	4500	
		2500	6000	
Drag Links lb	25	100	100	300
	50	200	250	1000
	100	300	500	1500
	150	500	750	3000
	250	800	1000	5000
	350	1200	1500	7500
		1800	2250	10000
			3000	
			4000	

Ceiling strut.- To measure forces on ceiling strut models a special balance is required. This balance should be part of the suspension system within the strut. Force measurements may be made by load cells or strain gages mounted on cantilever beams and must be designed for each strut and model installation.

Calibration.- Equipment is available to check out and calibrate the balances. Loads can be applied either singly or in combination using manually driven screwjacks. Strain gage links or load cells are used to measure the loads applied. Equipment is also available for checking and calibrating strain gage links against dead weights. When possible, the complete assembled model is calibrated both in the shop and in the tunnel. A jacket, provided by Lewis Research Center, is installed around the balance to maintain a constant temperature during the tunnel run. This eliminates changes in the calibration due to temperature variation.

Angle-of-Attack Indicator

A model angle-of-attack indicator system is available to ascertain the true model attitude. This makes it possible to correct for sting and strain gage balance deflections. The system consists of an angle-of-attack transmitter, shown in figure 17, installed in the model and a receiver located in the control room. The overall accuracy of the system is within 0.1°. The angle-of-attack range is between -45° and +45°. The wiring provided in the model for the transmitter should be four conductor shielded high temperature wire of size No. 18 or No. 22. Installation and calibration of this angle-of-attack indicator will be performed at Lewis Research Center.

A mock-up unit is available for fit checks and shop assembly of the model.

Thermocouples

Alloy wiring is connected from jacks on the upper and lower strut terminal panels to thermocouple junction reference units near the test section. The temperature of the wire junctions within these units is held to

101.1° C \pm 0.14° C (150° F \pm 0.25° F). Copper cables are run from these units to patchboards near the tunnel control room. A maximum of twenty-seven thermocouples of each type may be patched to each of three control room selector switches and read on digital temperature indicators. In addition, all thermocouples may be patched to inputs on the CADDE II data recording system (described in the section on DATA ACQUISITION AND PROCESSING).

Schlieren System

The tunnel is equipped with two identical schlieren systems which may be used independently or simultaneously. These systems are located at the upstream and intermediate sets of test section windows and are capable of showing the flow patterns in the test section for all positions of the 0.838 m (33 in.) diameter windows in the 1.52 m (5 ft) diameter disks. Figures 18 and 19 show the plan and elevation views respectively.

Schlieren images are viewed using the television systems and photographs of the images are taken by 70 mm Beattie Veritron automatic data recording cameras having a one microsecond exposure. A total of 325 photographs 6.35 x 8.57 cm (2-1/2 x 3-3/8 in.) may be taken without reloading. In addition, a Fastex 16 mm high-speed motion picture camera capable of taking 100 to 4000 frames per second is available for photographing the schlieren images.

DATA ACQUISITION AND PROCESSING

A wide range of data acquisition and processing equipment is available as follows:

Central Facility Data Recording

CADDE II. - CADDE II (Central Automatic Digital Data Encoder) data recording system is a low-speed voltage scanner and digitizer designed to convert steady state direct current signals to digital numbers at a rate of twenty-five samples per second. The raw data is recorded on

digital magnetic tape, which becomes the permanent data record. Optionally, the raw data can be sent to the central computing facility for further processing. A schematic diagram of the data system is shown in figure 20.

Up to 200 channels are available at the control room. The system accuracy is ± 0.05 percent of full scale. Full scale voltages, under programmed control, are as follows; ± 10 mV, ± 20 mV, ± 50 mV, ± 100 mV, ± 200 mV, ± 10 V, and ± 100 V. These 200 or fewer channels can be scanned in one of four ways:

1. Single scan: Each channel is sampled once, after which the scan is terminated. This is the method most frequently used.
2. Continuous scan: Each channel is sampled once; the system then automatically recycles and continues this process until a manual stop command is given.
3. Discontinuous scan: Same as continuous scan, except that the scanning can be halted for an arbitrary period and then resumed under manual control.
4. Intervalometer: Causes one scan of all channels and then halts for a pre-determined time (up to one hour) after which a new scan is initiated. The sequence is terminated by a manual stop command.

The raw data may be typed back to the facility control room for immediate inspection by the project personnel.

Multiple pressure scanning system.- Model pressures are sampled by means of Scanivalves. The Scanivalve unit contains a solenoid-actuated rotating pressure passage which sequentially connects 48 pressure lines to a single transducer. The CADDE system is used to step the Scanivalves and record the transducer signals. Up to eight of these Scanivalves are available for a test program. Of the available 48 ports per scanivalve, 5 are used for dynamic calibration signals and are thus unavailable for model instrumentation. Full scale pressure ranges available are; 1.03 N/m^2 (15 psia), 1.72 N/m^2 (25 psia), 3.44 N/m^2 (50 psia), and 6.90 N/m^2 (100 psia). An accuracy of ± 0.15 percent of full scale is maintained due to the dynamic calibration mechanism.

Since this pressure measuring system uses the CADDE II system, the total number of pressure signals is subtracted from the total channels available (500) to obtain the number of other signals that can be recorded.

Central analog recording system. - The Central Analog System records data on magnetic tape in IRIG standard format. Data is recorded on 12 tracks and a time code in IRIG A format is recorded on one track. Each of the data tracks are multiplexed to record in extended IRIG Constant Bandwidth consisting of 15 channels with a bandwidth of 4 kHz (MI=4). Full scale input voltages are ± 5 mV, ± 12.5 mV, ± 20 mV, ± 50 mV, ± 100 mV and ± 250 mV with an accuracy of ± 1.0 percent of full scale. All channels within a multiplexed track must have the same full scale input. Control of the recorder is remote at the facility.

For playback, up to 4 multiplexed channels can be displayed on strip chart recorders or light beam oscillographs. Automatic tape search based on record time is available. A limited amount of analog signal processing equipment is also available depending on the type of analyses desired.

Local Analog Recording System

A 14 channel tape recorder is located in the facility control room. One of the channels is used for IRIG B time clock and one for tape speed control, leaving 12 channels available for data. These channels may use any combination of Direct Record [300 Hz to 600 kHz at 305 cm/sec (120 in./sec)] or FM [DC to 40 kHz at 305 cm/sec (120 in./sec)] inputs. The input voltage is 0.1 to 10 volts on Direct Record or ± 1.0 volt to ± 25 volts on FM. Tape speeds are 2.38 cm/sec (15/16 in./sec) to 305 cm/sec (120 in./sec). Also available in the control room is a variety of signal conditioning and monitoring electronics.

Tape playback is accomplished either locally in the control room, or off-line at the central data facility.

Data Processing

The data recorded from a facility is reduced by a variety of high-speed digital and analog systems located at the Lewis Central Computer Facility. Digital computer programs are usually coded in FORTRAN IV level G, but BASIC, PL-1, APL, and assembled coding are also used for special cases.

On-line time sharing.- Data recorded on the CADDE II system can be automatically sent to the Lewis Time-Shared Computer Facility for on-line analysis. The computers used are two IBM model 360/67 units running in full duplex operation. The virtual memory hardware gives each user an apparent core size of four billion bytes (8 bits equal 1 byte), thus offering an almost unlimited capacity for data analysis. Raw data is stored on high-speed disc storage units for use in the analysis programs. A flexible data analysis and control package is used to process the raw data, apply the calibrations, and present engineering units to the analysis program. This analysis program contains all the calculations desired for a given test program.

The results of this analysis are processed by the output section of the system for display in the facility control room, either on electric typewriters or on a variety of high-speed graphic displays. Both listed numeric and graphic data can be presented. The data display is under control of the project engineer, making critical computed data available for decisions concerning future test points.

Off-line batch processing.- The bulk of the data is processed after the tunnel run is completed. Typically, the same program that is used for the on-line data is used in a batch mode on the time-sharing system. Data is then printed on high-speed printers or processed on off-line microfilm. The microfilm will accommodate both listed numeric data and graphic output.

In addition to the time-sharing system, data can be analyzed on an IBM 7090 direct couple system or on a UNIVAC 1106 system.

Off-line analog processing.- Off-line processing of analog data is handled by a variety of interconnected signal processing systems. In addition to strip chart and light-beam oscillograph recording, a Federal Scientific UA-6A spectrum analyzer is available, as are X-Y plotters, oscillographs and an analog computer. If digital processing is desired, data may be read from the analog tapes and digitized by the use of an SEL 810A computer with a 48 channel MUX and A/D converter. The output is a 9 track digital tape in the Lewis GIF format. This tape can be read on other Lewis digital computers for additional processing.

MODEL INFORMATION

Model Size

Figure 21 shows the approximate maximum projected frontal area (model plus support strut) for tunnel starting. Since the limiting model size is influenced by such factors as model shape and location in the test section, each model proposal must be evaluated independently.

Model Design Criteria

Tunnel test models should be designed for the following applicable load conditions:

Steady-state loads.- The allowable stresses for the maximum loading conditions should not exceed $1/5$ of the ultimate stress or $1/3$ of the yield stress, whichever is least. In addition, for members loaded as columns, the Euler critical load should be at least three times the applied load.

Supersonic starting loads.- For starting loads, the design should be based on a 10° air flow direction added to the angle of attack of the model at tunnel starting. The dynamic pressure used should be maximum tunnel dynamic pressure as given by figure 3(b) or figure 4(b). When using this criteria the allowable stresses should not exceed $1/2$ of the yield stress. This technique for considering starting loads is given as a general guide. Therefore; models unusual in size, shape, or operation, may require special analyses.

All auxiliary parts of the model exposed to the air stream and nominally at zero angle of attack should be evaluated at 10° angle of attack.

Pressure Instrumentation

The recommended pressure tubing size is 1.59 mm (1/16 in.) outside diameter and 0.30 mm (0.012 in.) wall thickness. Static pressure orifices should be flush with and perpendicular to model surfaces.

Sting-mounted models built for testing in the tunnel should have the tubing extend at least 0.91 m (3 ft) beyond the sting socket to allow for connections. For models mounted on a ceiling strut the tubing should extend at least 3.05 m (10 ft) beyond the top of the strut.

Rakes should be designed to avoid resonance with model operating mechanisms. All rakes located upstream of an engine or other rotating machinery must be vibration tested before use. Any brazing required on rakes should be the silver-braze type. Rake tubes should be spaced to measure equal areas facilitating pressure integration. A filler plate should be provided to replace each removable rake.

Thermocouple Wiring

All model thermocouples should be made with high-temperature glass-insulated thermocouple wire of as heavy a gage as practical. Leads extending from the model should be long enough to reach the appropriate strut terminal panel and should terminate in Thermo Electric Co. Type 2PSS plugs.

The following table lists the type and number of thermocouple circuits available at each strut terminal panel:

Terminal Panel	Quan.	Wire Type (ISA)	
Sting strut	65	Iron/constantan	Type J
"	20	Chromel/alumel	Type K
"	25	Copper/constantan	Type T
Ceiling strut	40	Iron/constantan	Type J
"	45	Chromel/alumel	Type K
"	20	Copper/constantan	Type T
"	20	Platinum, 13% Rhodium/Platinum	Type R

Actuators and Position Indicators

To accomplish remote positioning of wind tunnel model components, screwjacks and hydraulic cylinders are commonly used. Electrically driven screwjacks should be provided with limit switches to protect the model and mechanism from damage due to overtravel. Hydraulic cylinders should be sized so their travel cannot exceed safe limits and they should be of the cushioned type if they are to move rapidly. The hydraulic system available has a capacity of $3.79 \times 10^{-3} \text{ m}^3/\text{sec}$ (60 gal/min) at $2.07 \times 10^7 \text{ N/m}^2$ (3000 psi).

Remote position indication is often provided by a linear or rotary potentiometer. Each potentiometer should have a total resistance of 1000 ohms and be linear within 0.1 percent.

Electrical Cables

Electrical cables from the model are terminated in connectors which mate with an existing cable system extending between the tunnel test section area and the control room. The types of cables available are:

Power cables.- Type "A" cables are used for heavy power circuits (greater than 2 amperes at 28 volts or 5 amperes at 120 volts). Several of these circuits may be grouped in a single cable. Type "C" cables are used for small motors, limit switches, selsyns, and so forth. Several of these circuits may also be grouped in a single cable.

Signal cables.- Type "X" cables are used only for strain gage type transducers, as each terminates in a signal conditioner in the control room. Type "B" cables are used for other circuits requiring shielded wires, such as potentiometers and servovalves. Type "K" cables are coaxial type and are used for piezoelectric transducers.

Each device should use an individual cable. Differential transformers should use separate cables for power and signal. The shield of each cable is fastened to the connector cable clamp.

The types and numbers of model cables and the termination details are given in the following tables:

Sting Strut Terminal Panel

Type	Quan.	Cable	Cable Terminal Connector	Required Mating Connector
A	5	6 conductor No. 9 AWG	MS 3100A-24-10S	MS 3106A-24-10P
C	8	12 conductor No. 16 AWG	MS 3100A-24-19S	MS 3106A-24-19P
B	16	6 conductor No. 20 AWG shielded	MS 3100A-14S-6S	MS 3106A-14S-6P

Ceiling Strut Terminal Panel

Type	Quan.	Cable	Cable Terminal Connector	Required Mating Connector
A	8	6 conductor No. 9 AWG	MS 3100A-24-10S	MS 3106A-24-10P
C	20	6 conductor No. 16 AWG	MS 3100A-16S-1S	MS 3106A-16S-1P
B	100	6 conductor No. 20 AWG shielded	MS 3100A-14S-6S	MS 3106A-14S-6P
X	100	8 conductor No. 22 AWG 4 shielded pairs	MS 3100A-18-1S	MS 3106A-18-1P
K	20	RG 58/U coaxial	BNC male	BNC female

FACILITIES AVAILABLE TO USERS

Model Stands

Six model-mounting stands are located in the shop area for assembly and check-out of a model prior to tunnel installation. Four are for sting mounted models and two for ceiling strut models.

For the sting-mounted model stand, the sting centerline is 1.22 m (4 ft) above the floor or 1.52 m (5 ft) if a spacer is used. A connector panel is available at each stand which is identical to the panel installed in the strut for connecting instrumentation. This panel makes it possible to check all instrumentation in the model prior to tunnel installation.

For the ceiling strut model stand, the model is suspended by its strut from an overhead support between two columns 5.44 m (17 ft 10 in.) apart. The support itself is 3.28 m (10 ft 9-1/4 in.) above the floor. The model may be hung at a convenient adjustable working height. The stand can be positioned in three different places on the floor, each 1.52 m (5 ft) apart, for working clearance between the model and the shop wall.

Machine Tools and Lifts

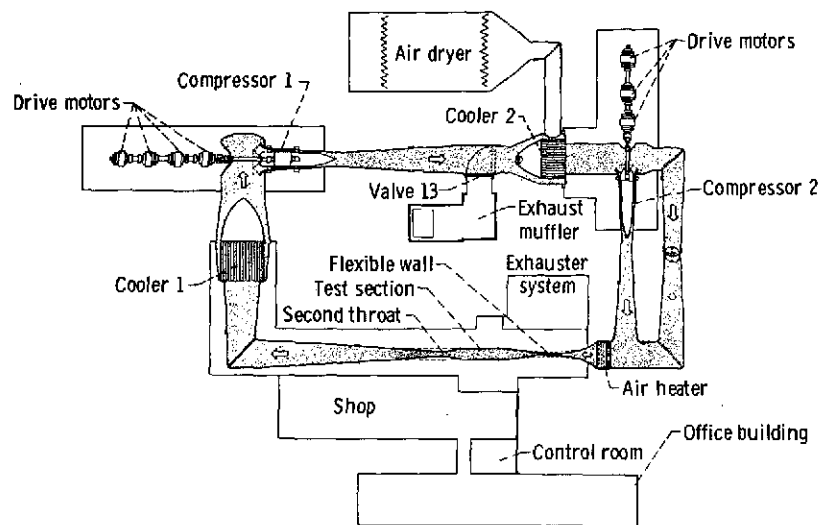
The wind tunnel shop contains an overhead 18 100 kg (20 ton) capacity crane and a collection of machine tools including two lathes, a milling machine, Do-All band saw and several drill presses and bench grinders. For sheet-metal work, a 0.91 m (3 ft) light gage roll, 1.52 m (5 ft) light gage bending brake, 1.22 m (4 ft) light gage shear, 0.61 m (24 in.) throat punch, and a throatless shear are available. Various size surface plates are available for setup and layout work. There are several types of hand trucks and a 0.61 x .91 m (2 x 3 ft) elevating table with a capacity of 900 kg (2000 lb.).

A tool crib located in the shop area has a complete line of hand tools including some hand power tools. Also available are acetylene, electric, and heliarc welding equipment as well as a small spot welder.

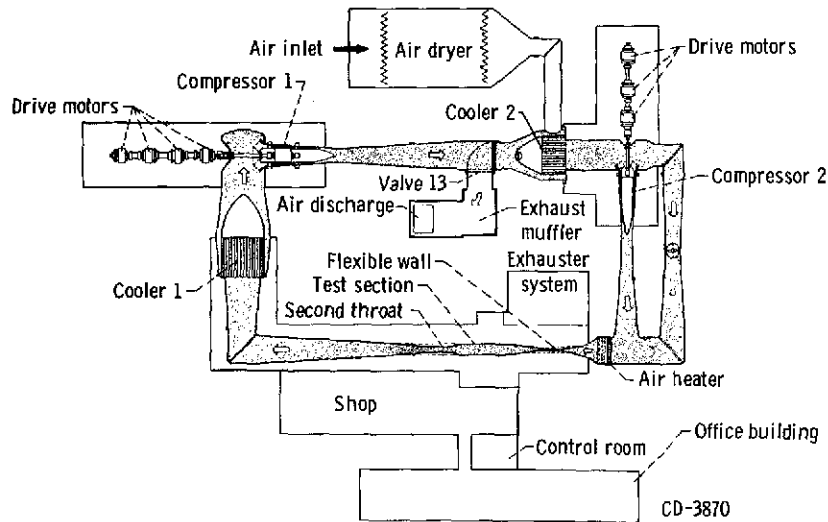
Electrical Systems

At either the shop model stand or the tunnel test section the following types of electrical power are available:

440 volt,	60 cycle,	3 phase,	A.C.
208 volt,	60 cycle,	3 phase,	A.C.
120 volt,	60 cycle,	1 phase,	A.C.
208 volt,	400 cycle,	3 phase,	A.C.
120 volt,	400 cycle,	1 phase,	A.C.
26 volt,	400 cycle,	1 phase,	A.C.
28 volt,	D.C.		



(a) Aerodynamic cycle



(b) Propulsion cycle

Figure 1.

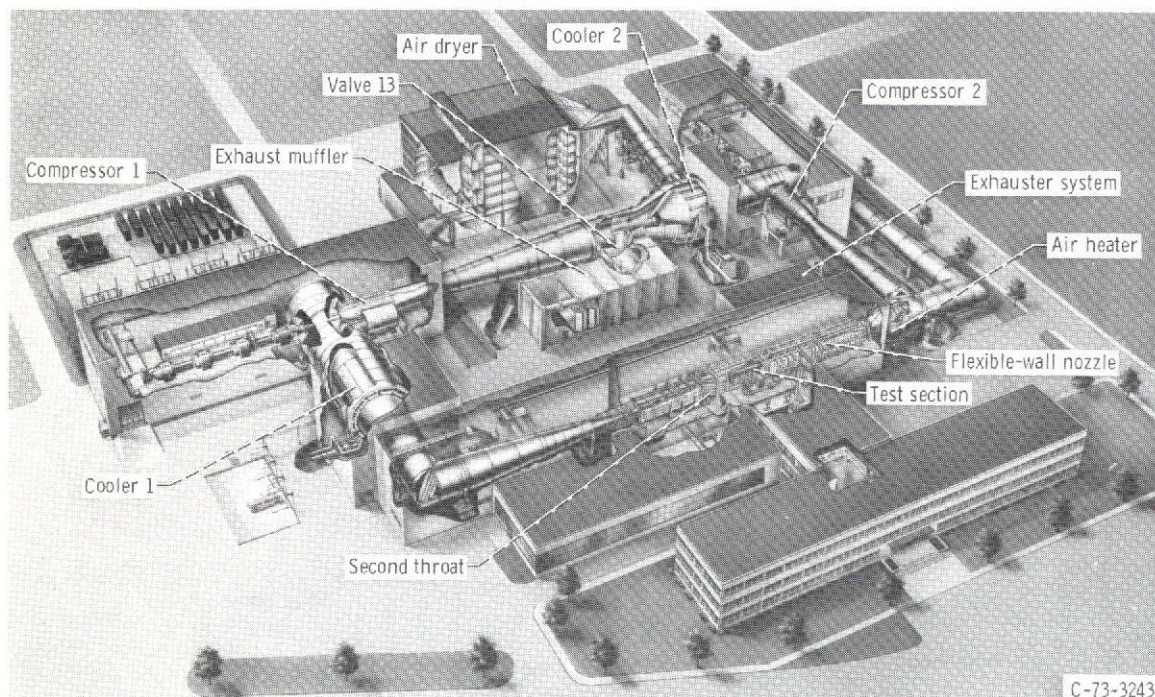
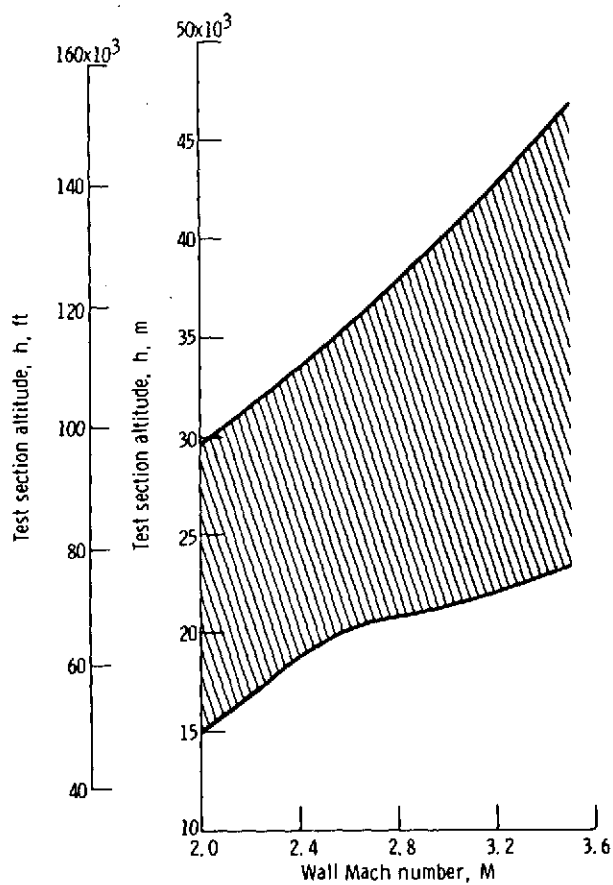
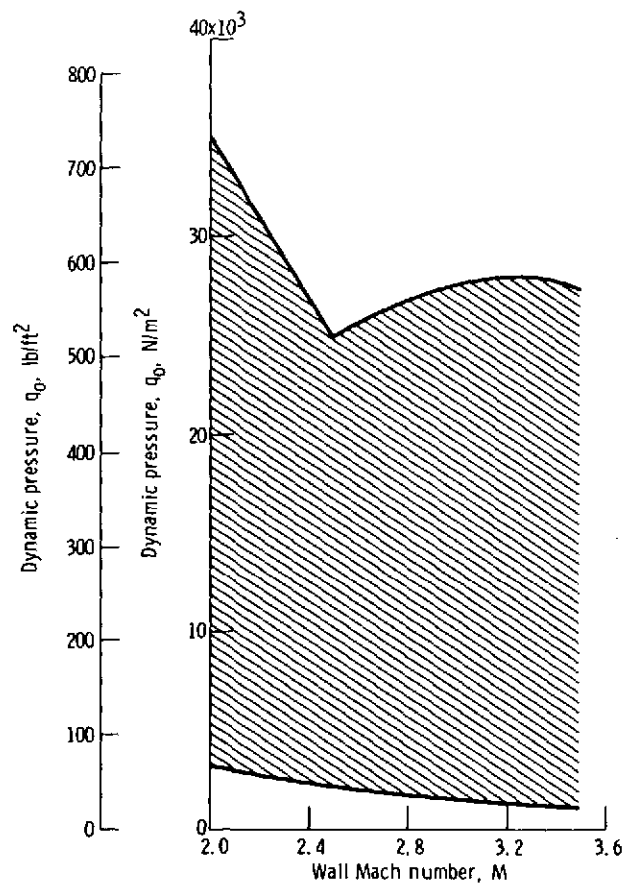


Figure 2.

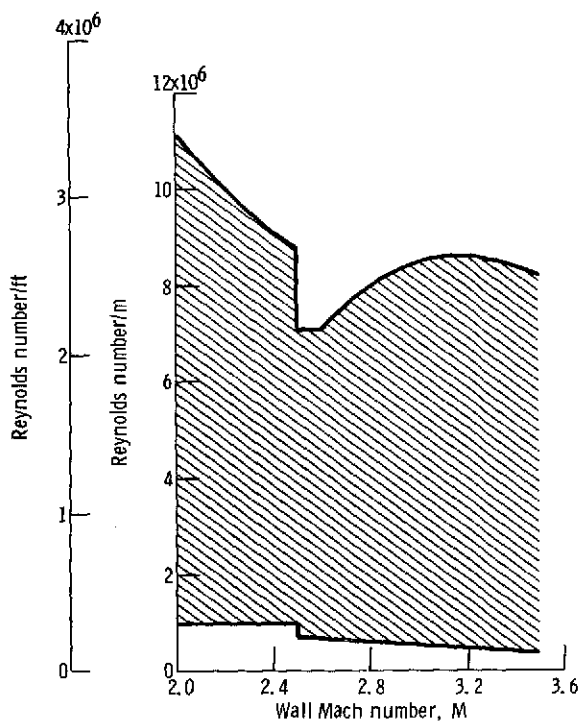


(a) Altitude.

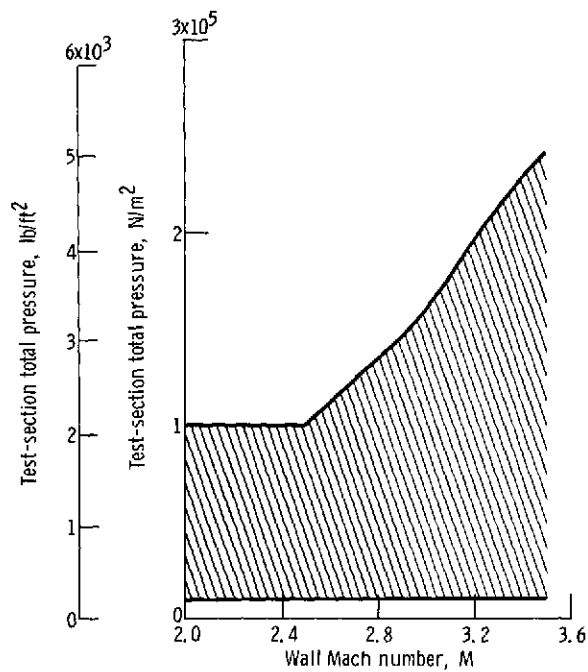


(b) Dynamic pressure.

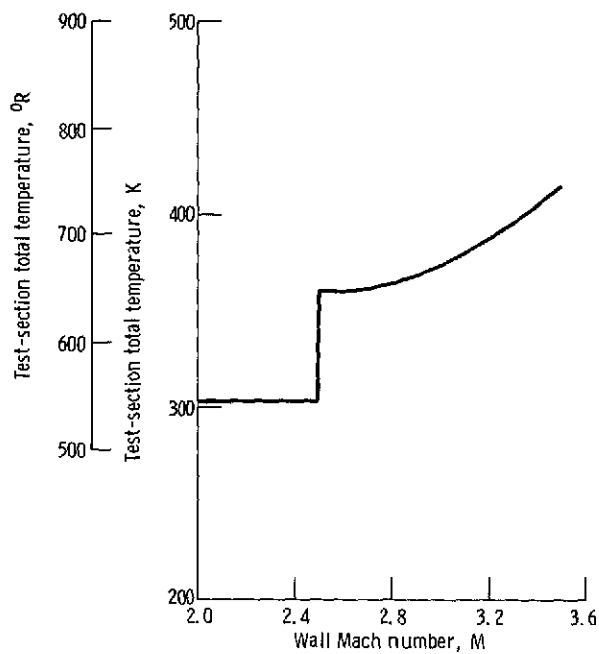
Figure 3. - 10- by 10-foot supersonic wind tunnel (aerodynamic cycle).



(c) Reynolds number.

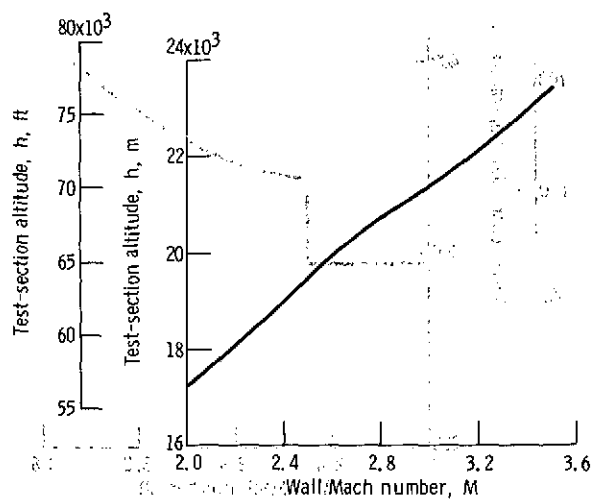


(d) Total pressure.

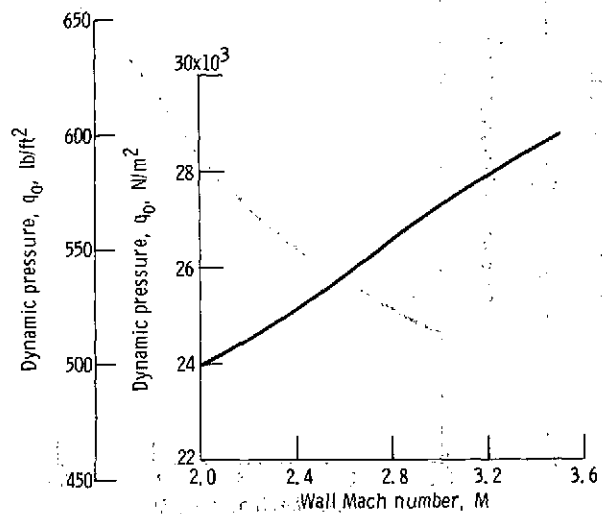


(e) Total temperature.

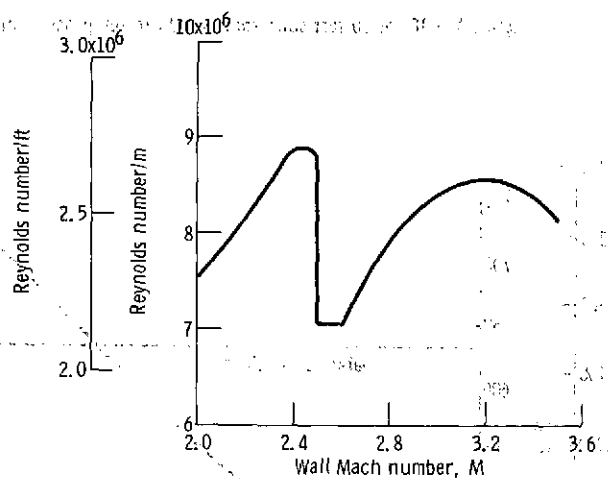
Figure 3. - 10- by 10-foot supersonic wind tunnel (aerodynamic cycle).



(a) Altitude.



(b) Dynamic pressure.



(c) Reynolds number.

Figure 4. ~ 10- by 10-foot supersonic wind tunnel (propulsion cycle).

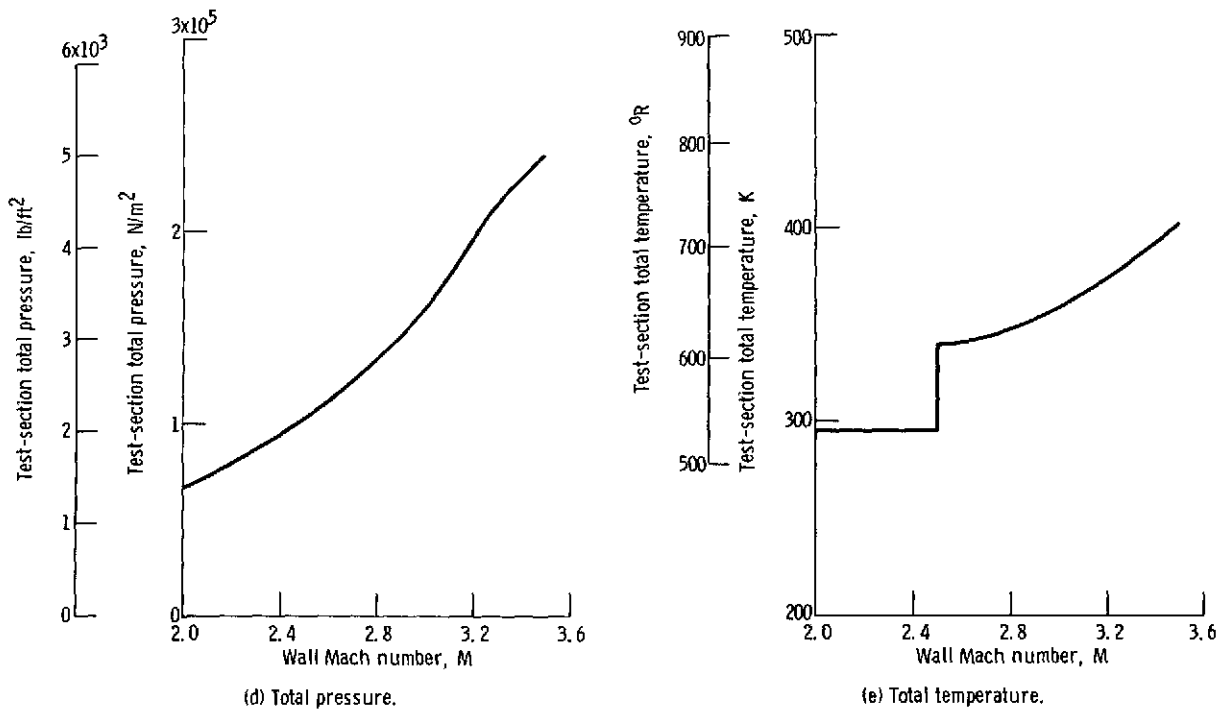


Figure 4. - 10-by 10-foot supersonic wind tunnel (propulsion cycle).

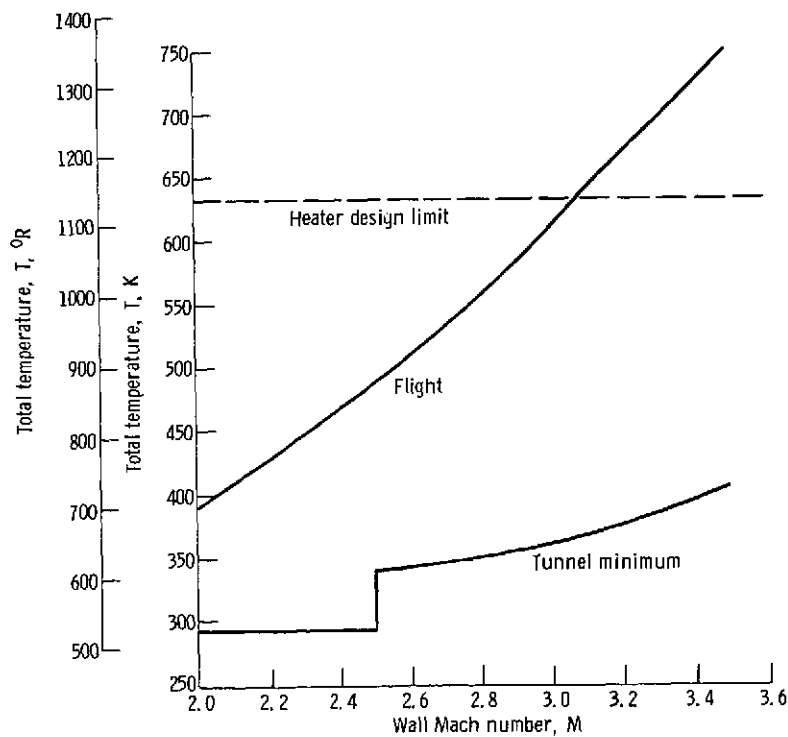


Figure 5. - Variation of free stream total temperature with Mach number. 10-by 10-foot supersonic wind tunnel.

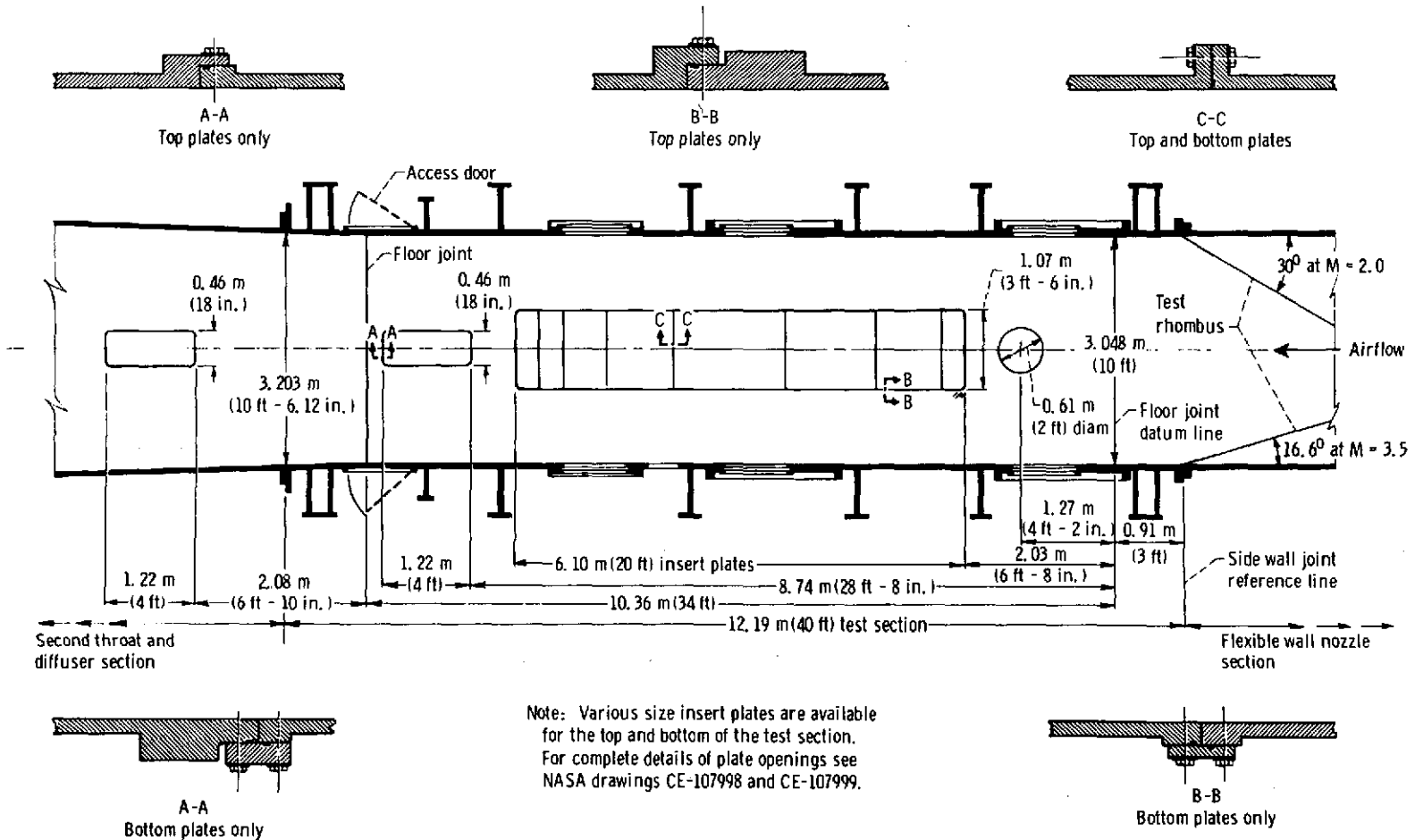


Figure 6. - Ten-by-ten-foot test section plan view.

CD-4113

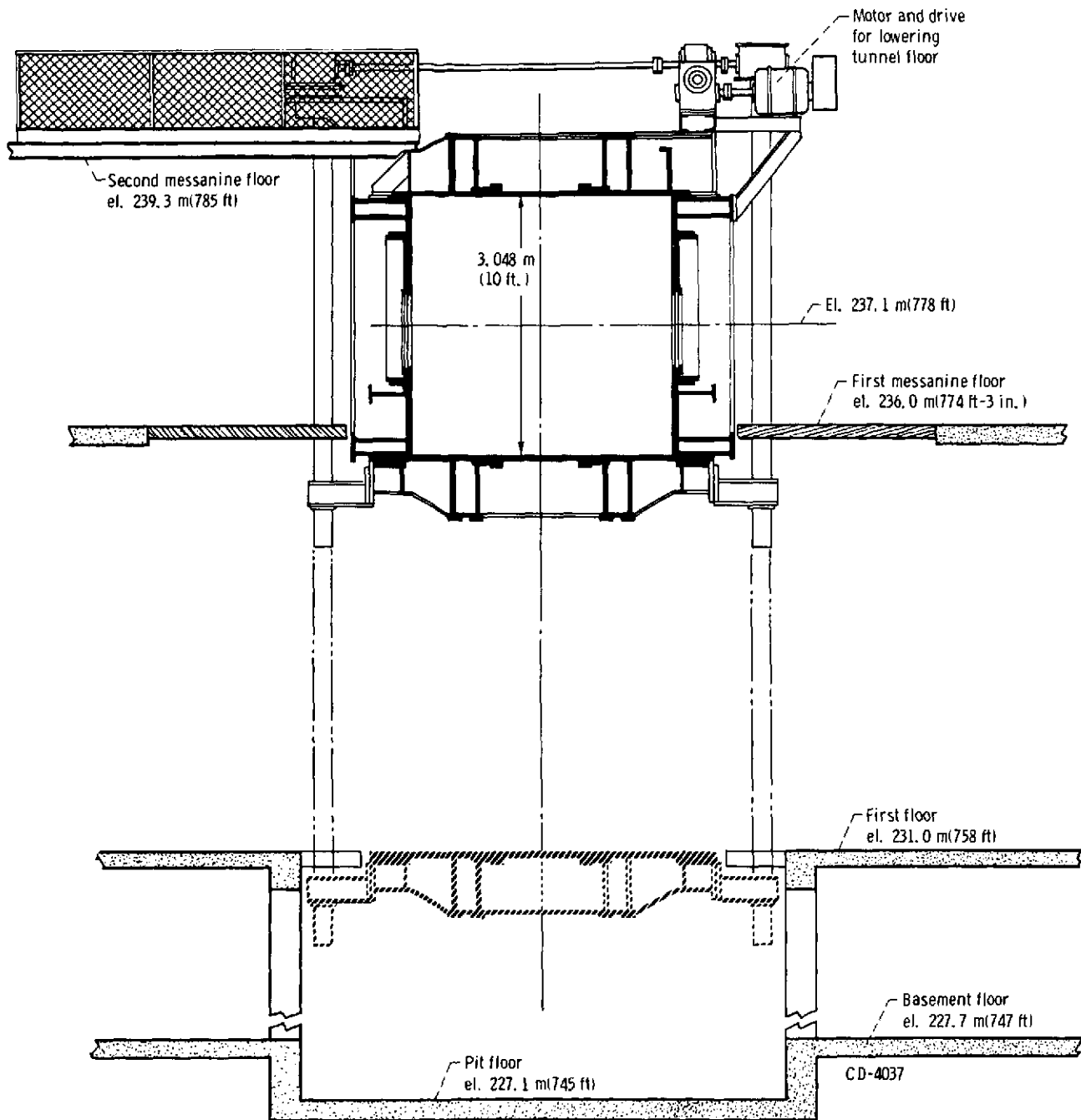


Figure 7. - Ten-by ten-foot test section cross section.

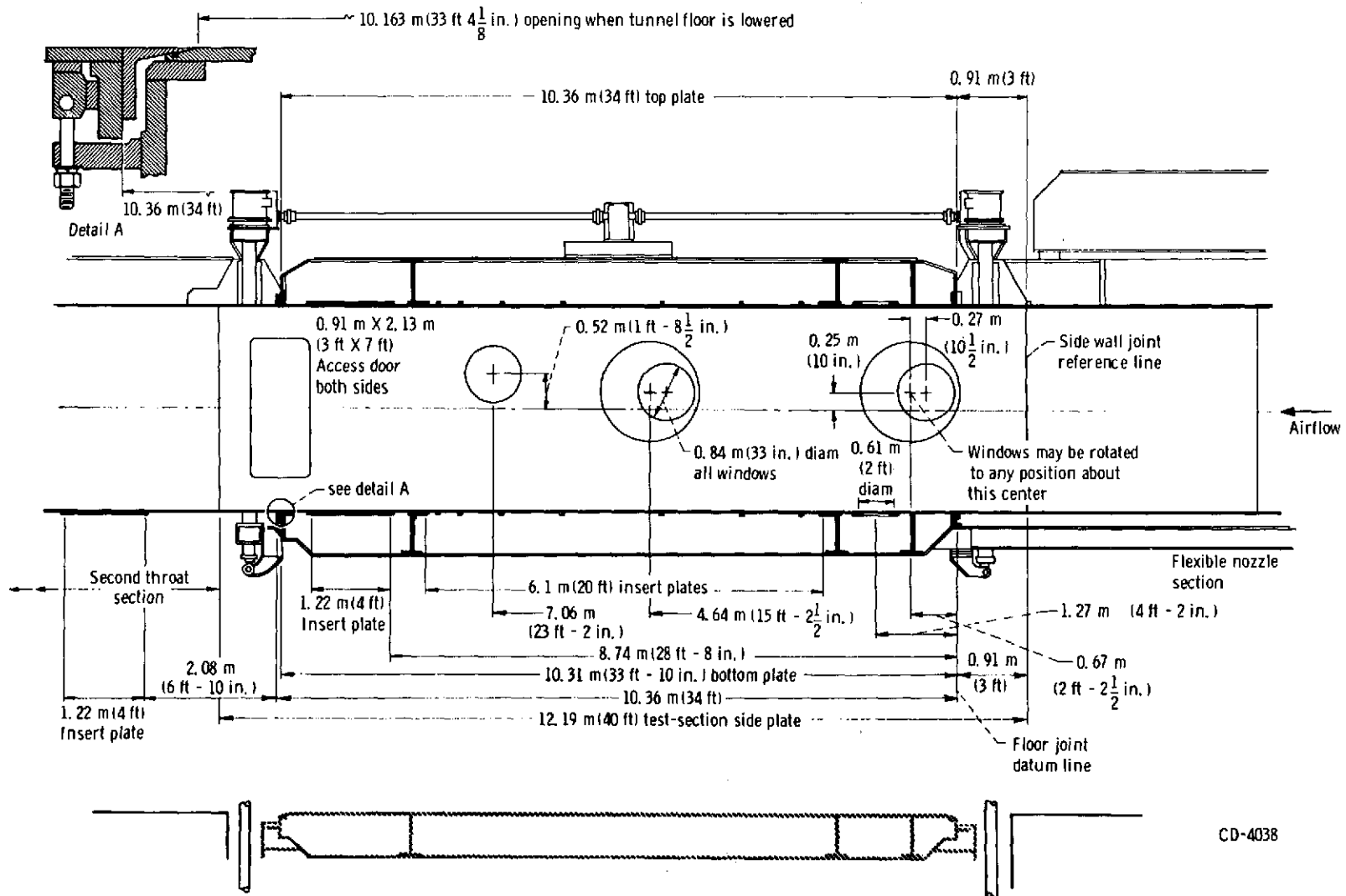
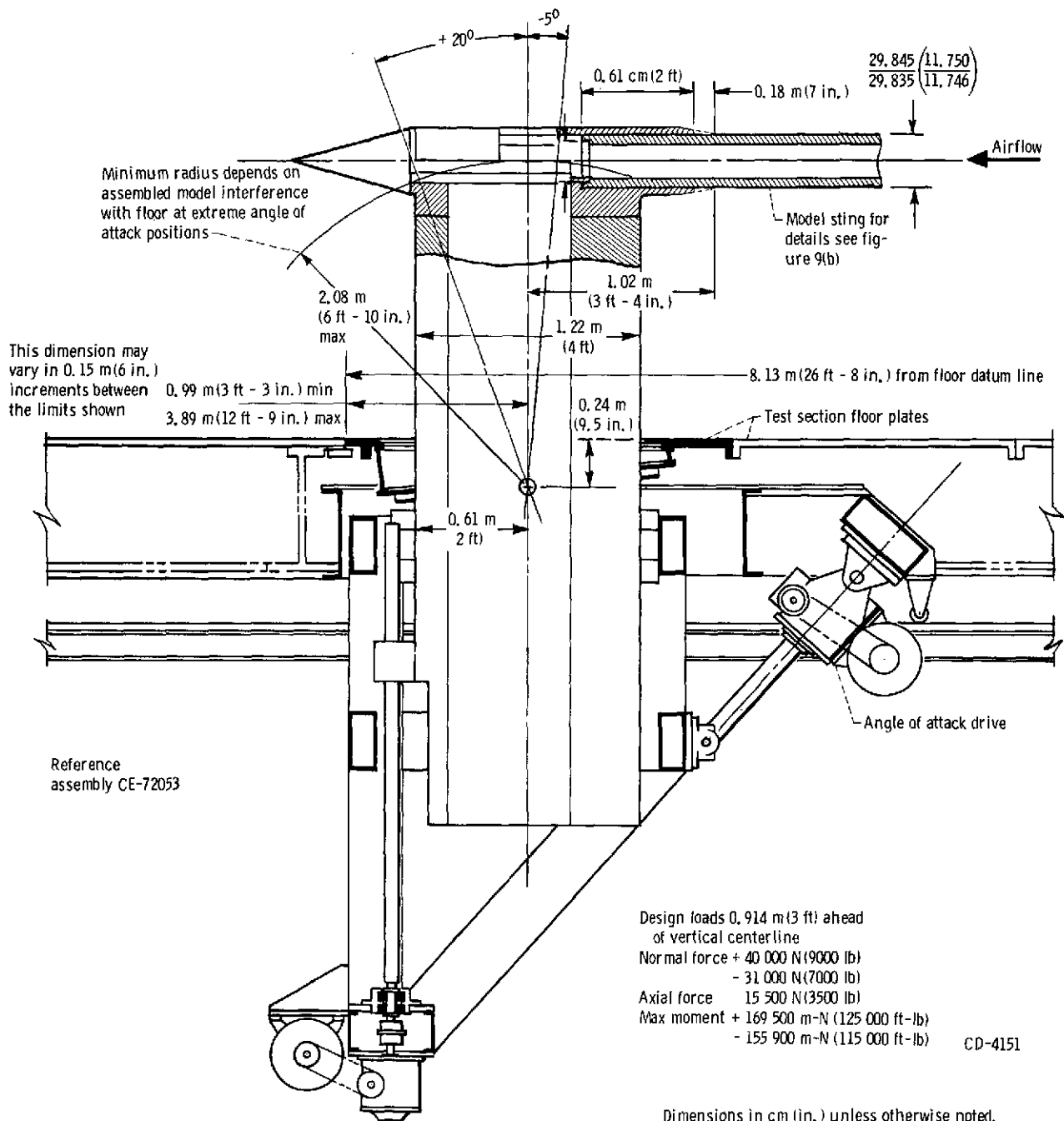
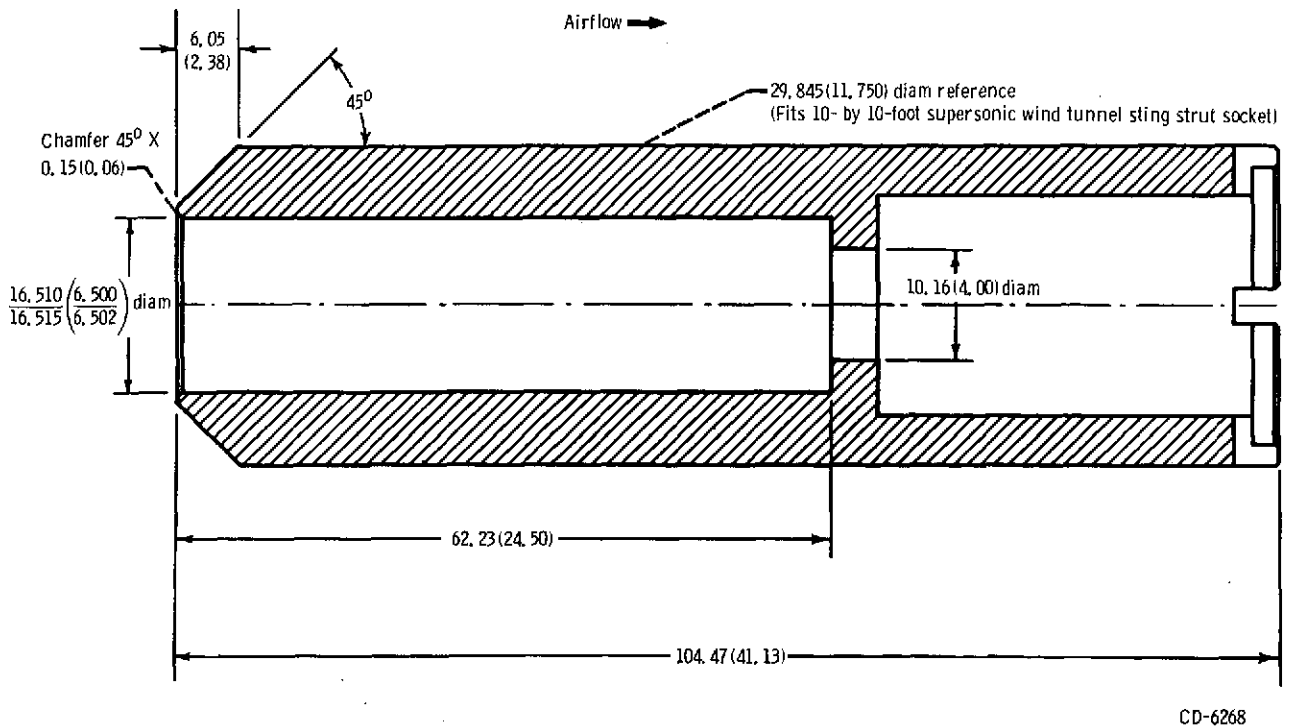
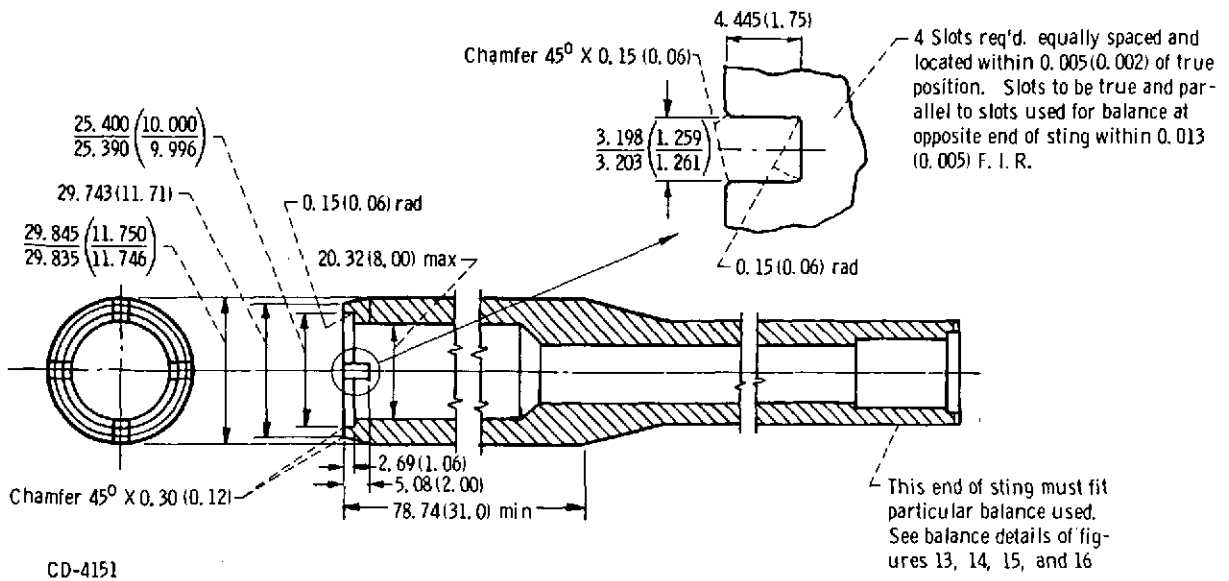


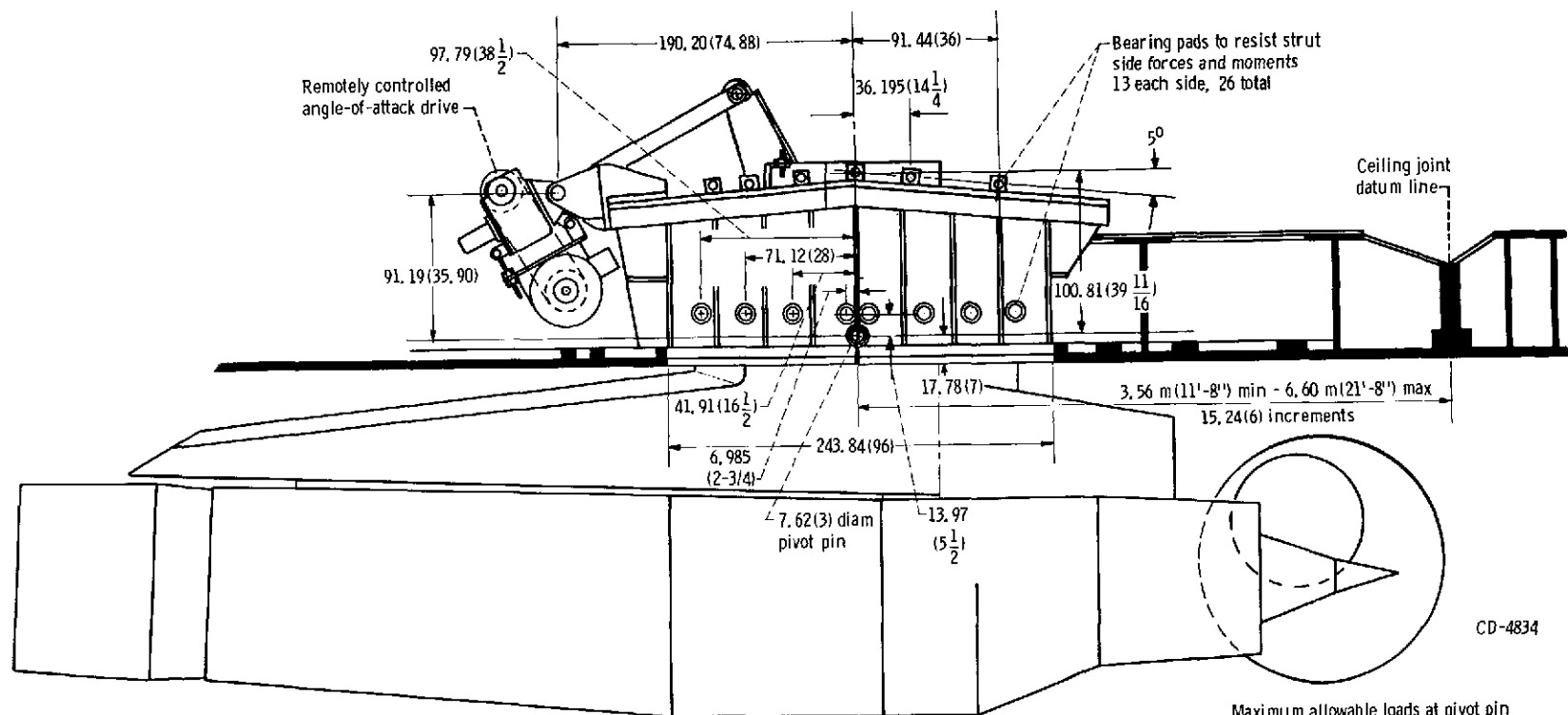
Figure 8. - Ten-by-ten-foot test section elevation view.



Dimensions in cm (in.) unless otherwise noted.

Figure 9(a). - Sting strut.





References

Assembly, strut support CR-72200
Installation, model CF-74320

Maximum allowable loads at pivot pin

Normal force $\pm 222\,400$ N (50 000 lb)
Axial force $\pm 222\,400$ N (50 000 lb)
Pitching moment $\pm 237\,200$ m-N (175 000 ft-lb)

Dimensions in cm (in.) unless otherwise noted.

Figure 11. - Ceiling strut support.

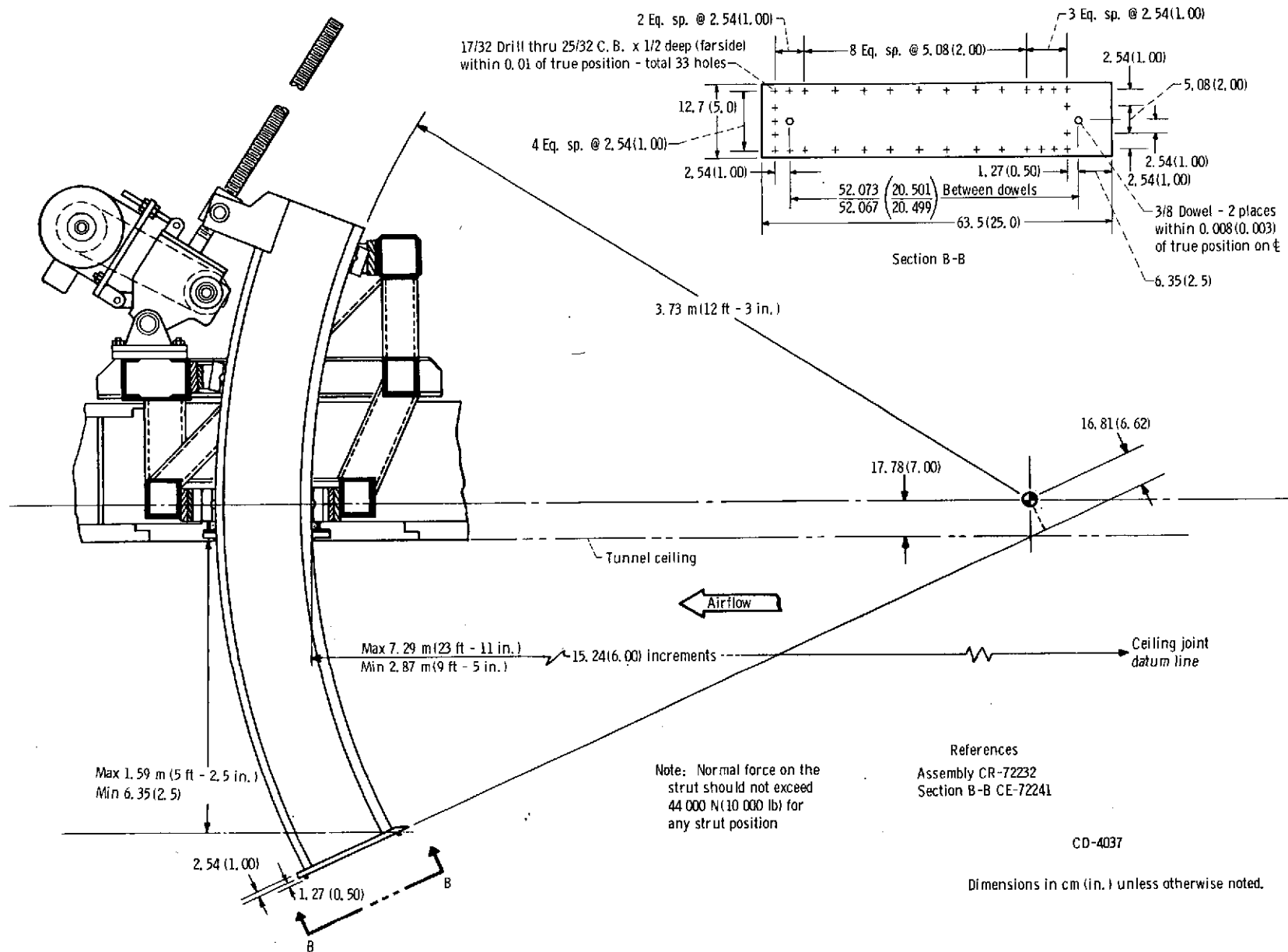


Figure 12. - Auxiliary strut.

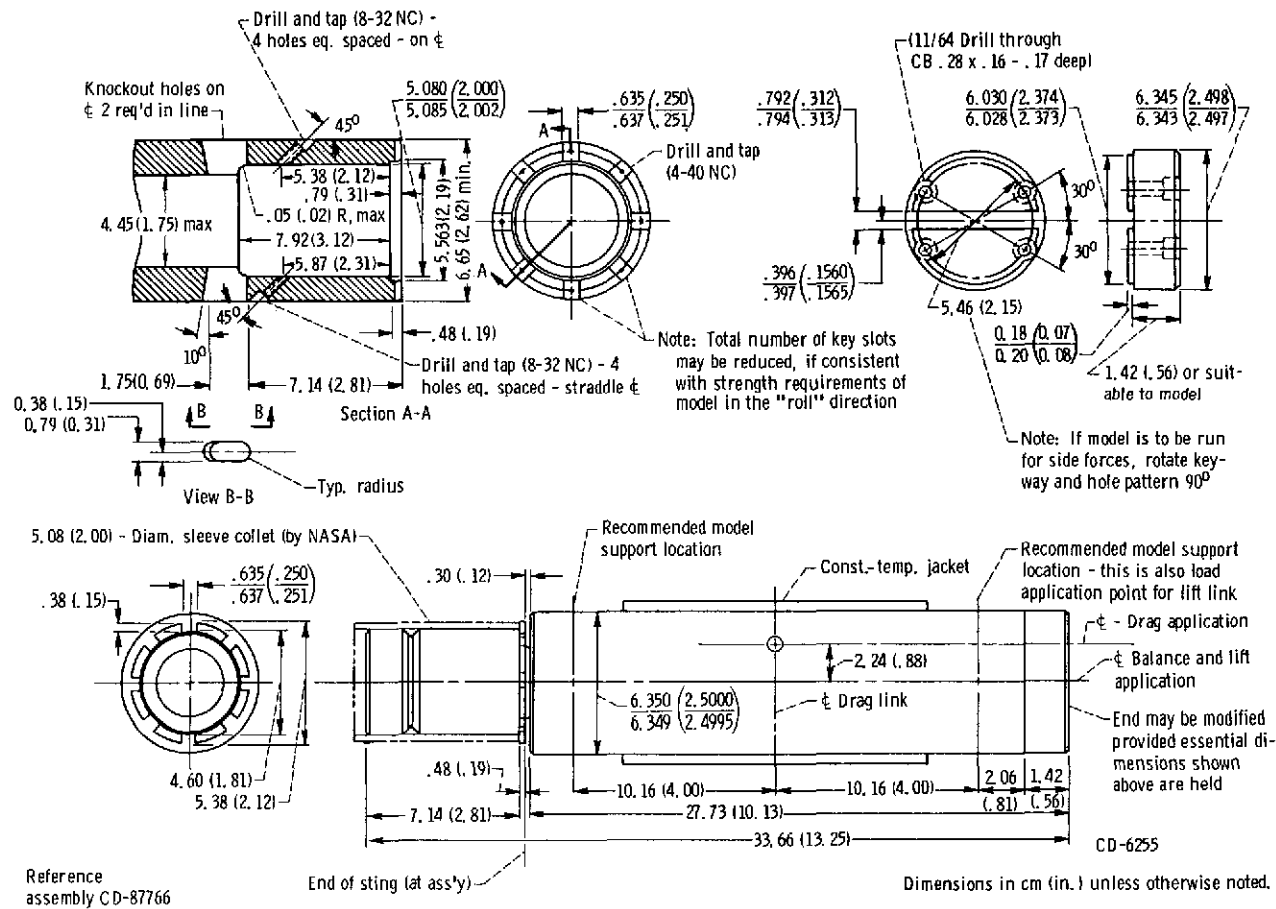
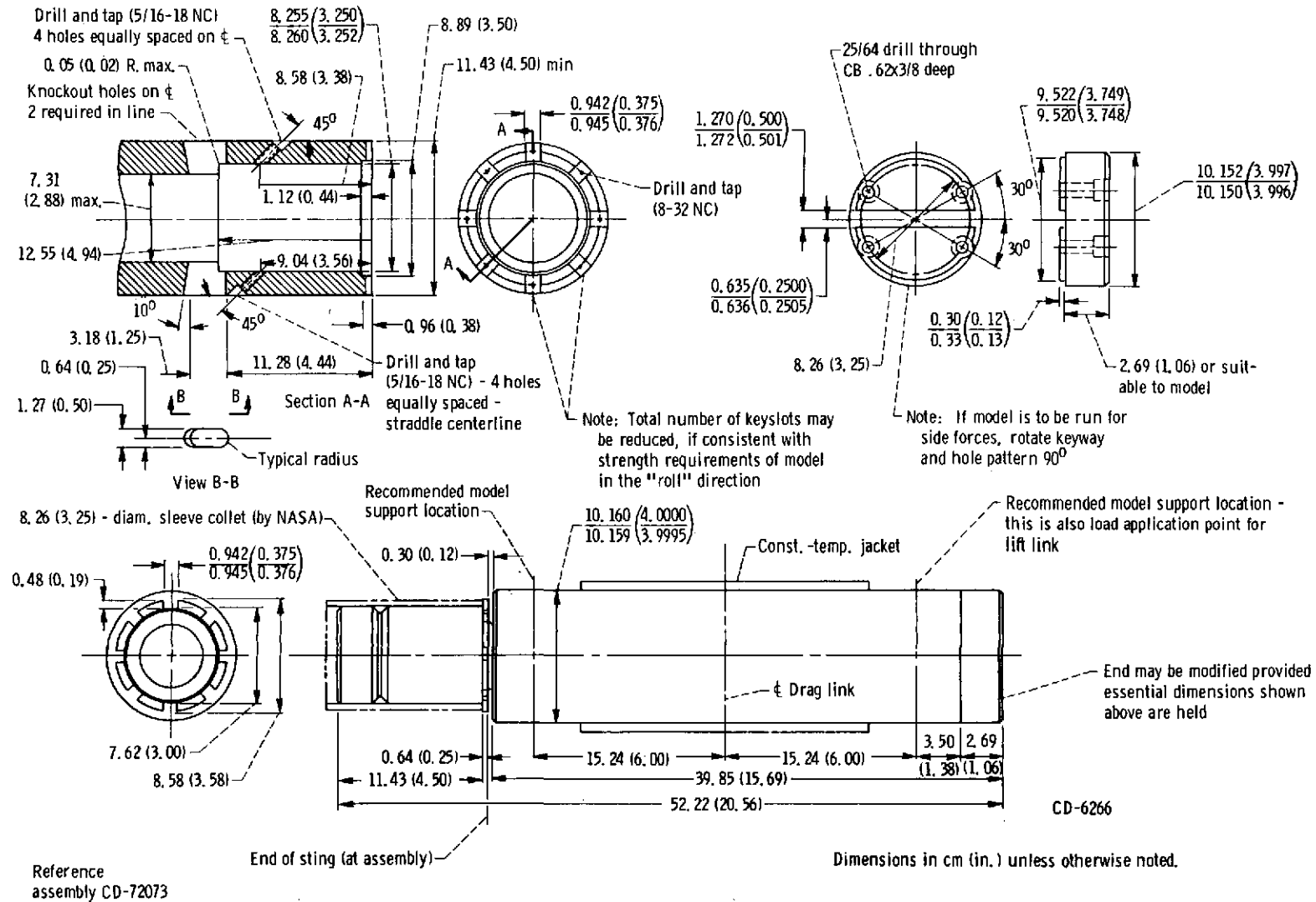


Figure 13. - 2 1/2-Inch strain gage balance.



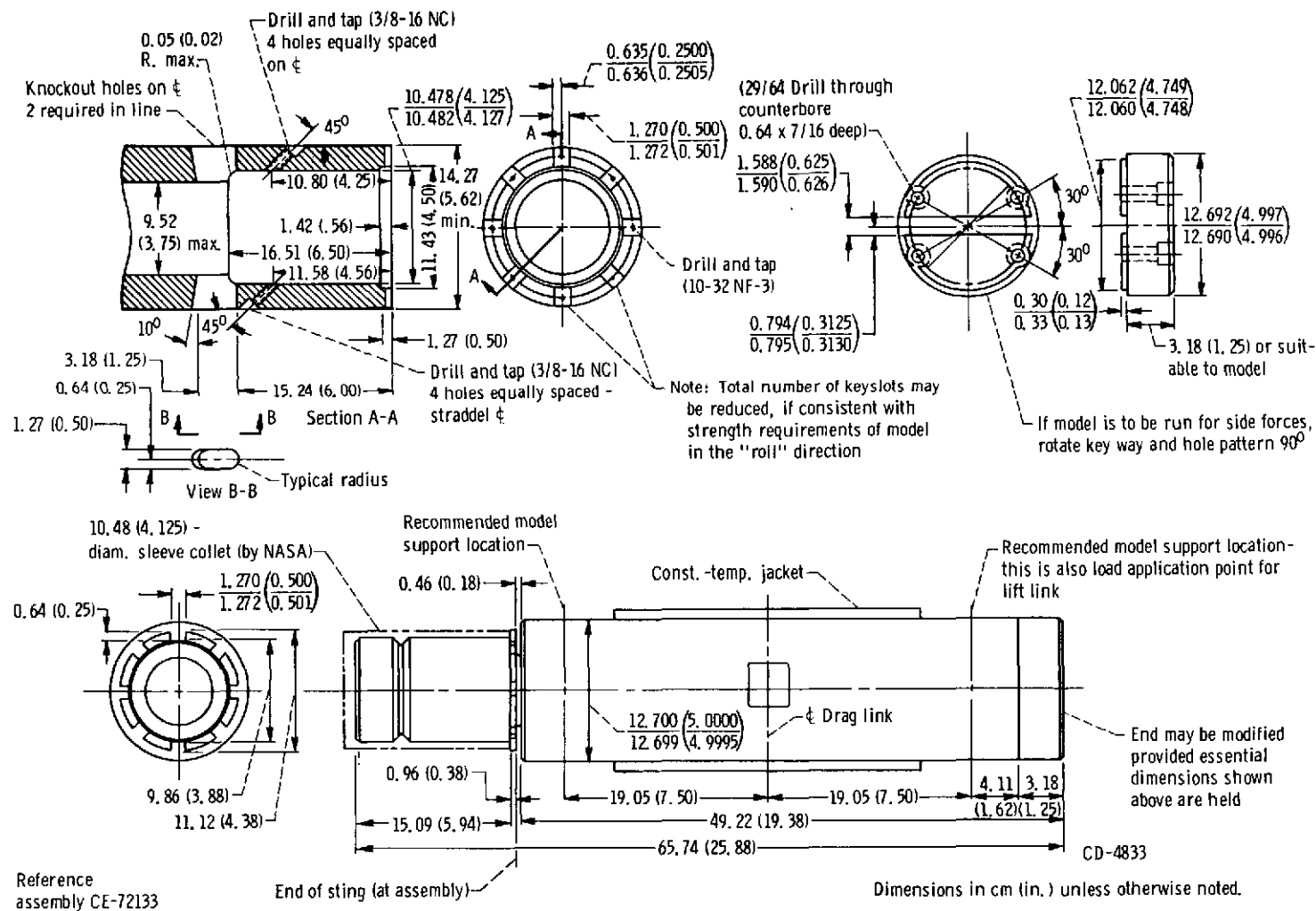


Figure 15. - 5-Inch strain gage balance.

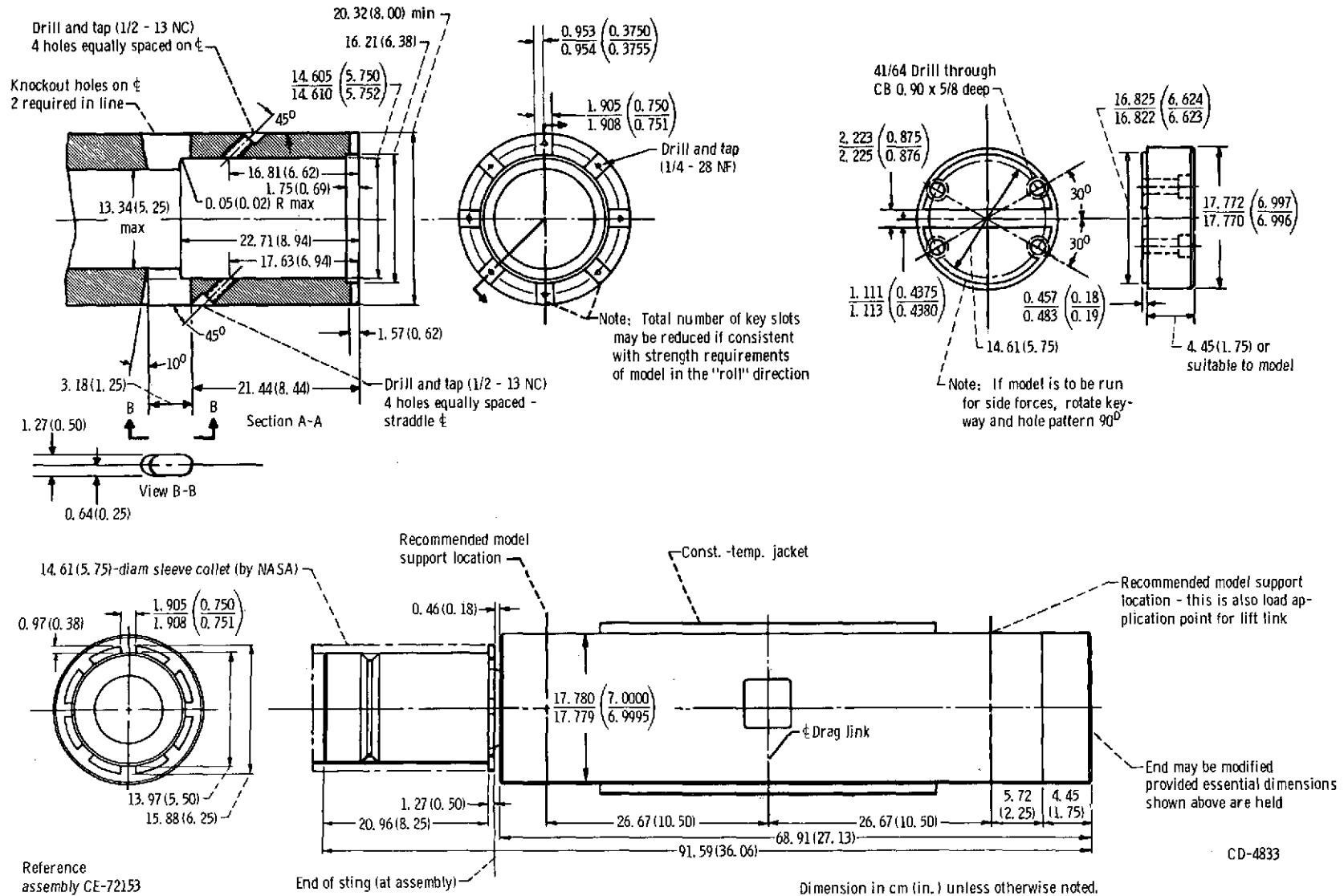
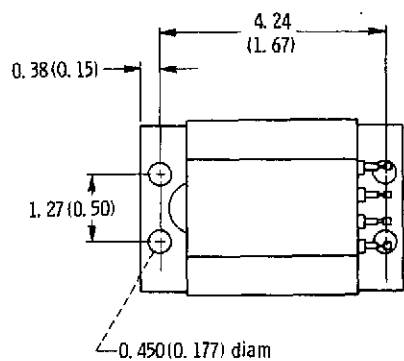
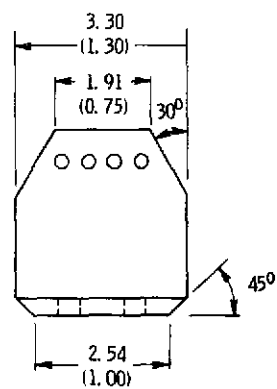
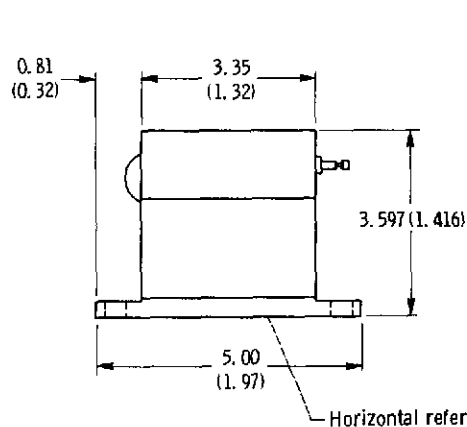


Figure 16. - 7-Inch strain gage balance.



References:
 Transmitter details - CF 89287
 Electrical installation - MDS 900



Dimensions in cm (in.)

Figure 17. - Angle-of-attack transmitter.

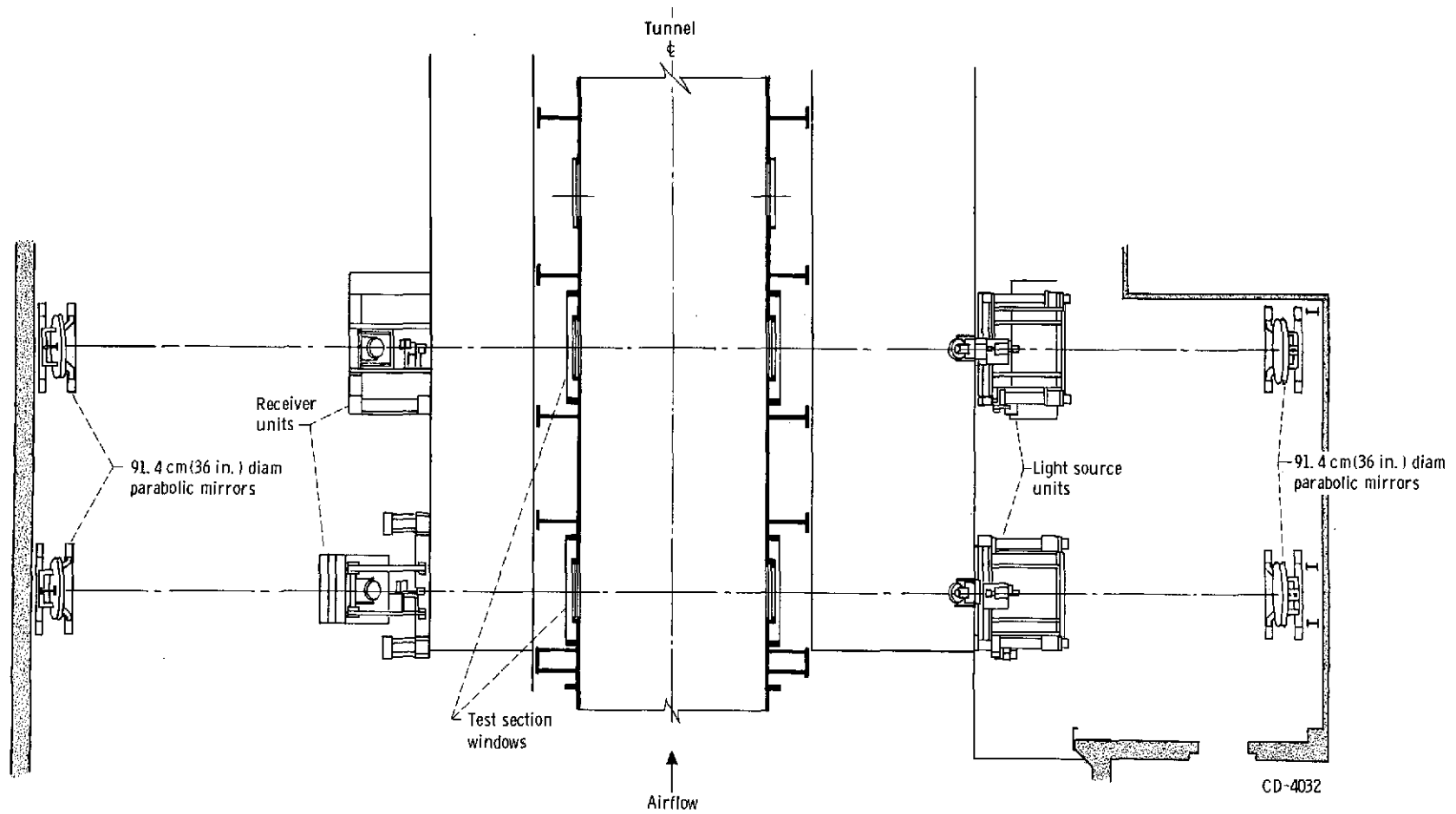
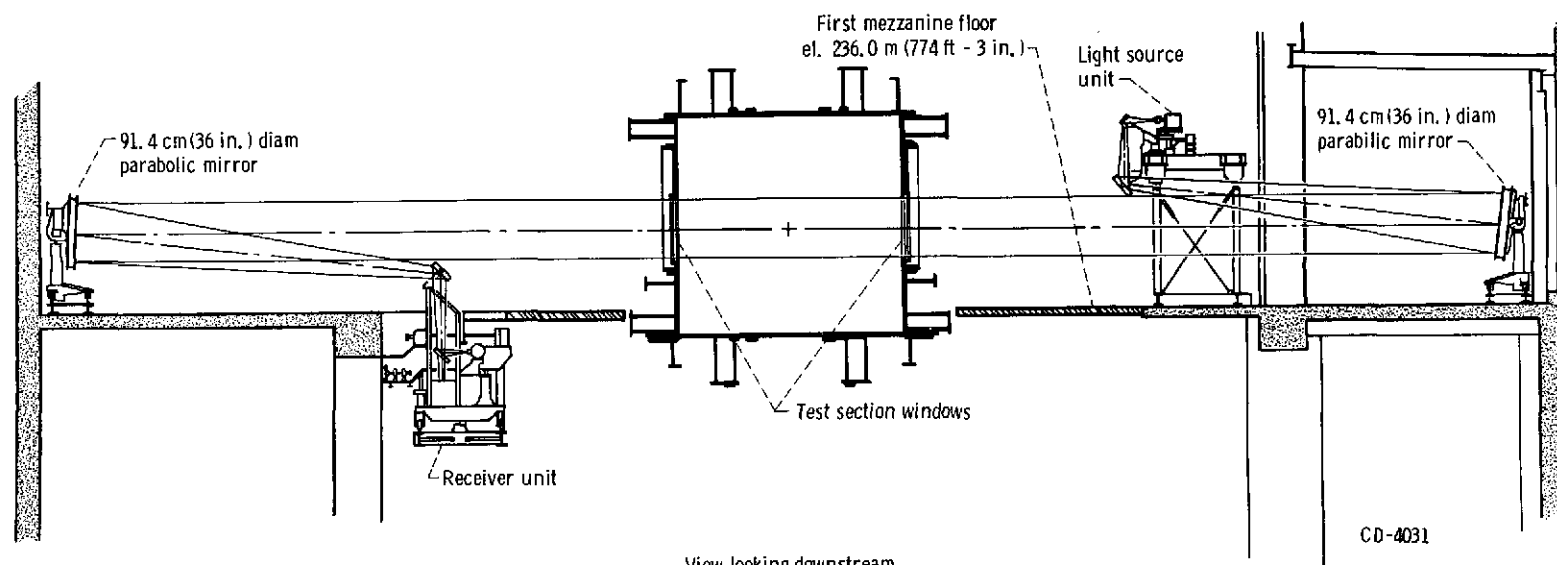


Figure 18. - Schlieren system plan view.



View looking downstream
 Figure 19. - Schlieren system elevation view.

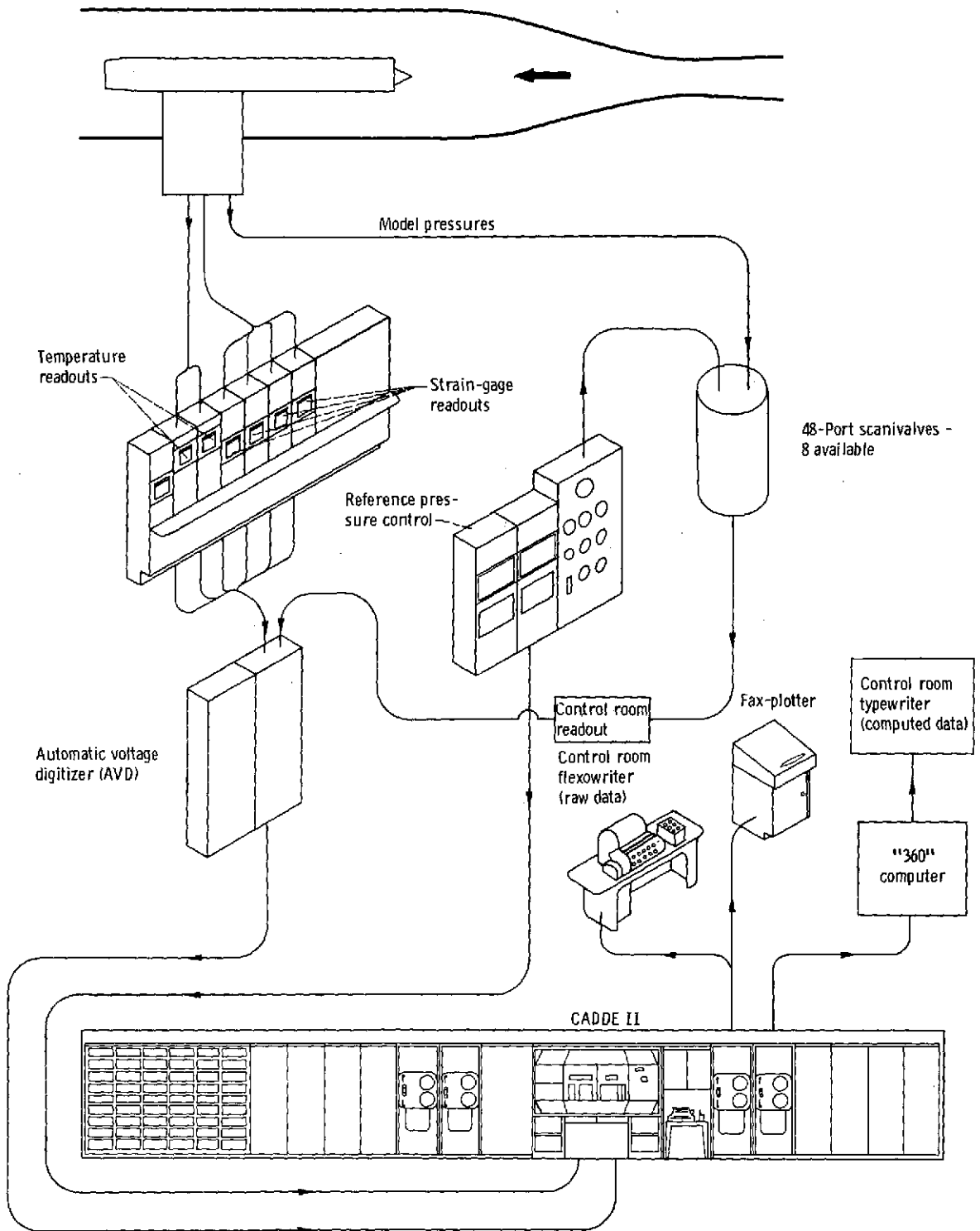


Figure 20. - Automatic data recording and processing system.

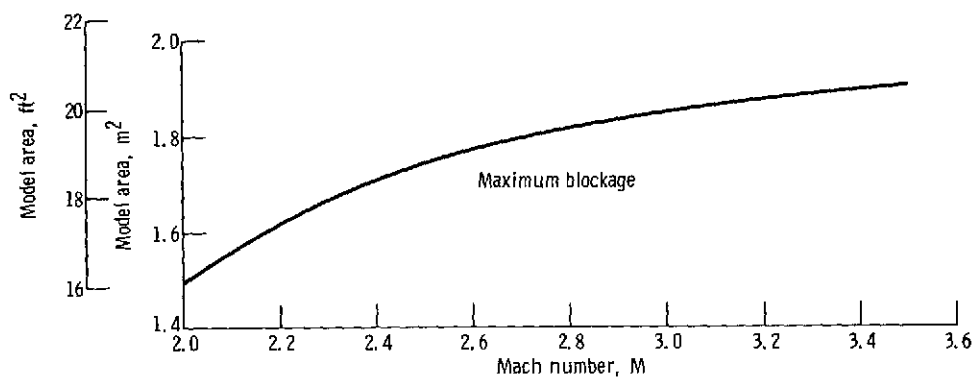


Figure 21. - 10-by 10-foot supersonic wind tunnel starting limitation.

E-8151